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Extending Comprehensive Maritime Awareness to Disconnected Vessels and Users

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Extending Comprehensive Maritime Awareness To Disconnected Vessels & Users

by

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13. ABSTRACT (maximum 200 words)

After the attacks of 9/11, increasing security became a national priority that has grown steadily since that date. National Maritime Security is one area of focus that has expanded into several new programs. Maritime Domain Awareness (MDA) is an initiative developed by the Coast Guard, in partnership with the U.S. Navy and other agencies to increase awareness in the maritime domain in support of maritime security.

The purpose of MDA is to generate actionable intelligence obtained via the collection, fusion and dissemination of information from U.S. joint forces, U.S. government agencies, international coalition partners and commercial entities. This actionable intelligence is the cornerstone of successful counterterrorist and maritime law enforcement operations and is critical to Maritime Security.

The U.S. Navy, as a partner in the development and creation of MDA, has tasked its subordinate commands to identify and define capabilities to support this program. One effort sponsored is the Comprehensive Maritime Awareness (CMA) Joint Capabilities Technology Demonstration (JCTD). This project supports the CMA JCTD efforts by proposing a deployable system to enable a disconnected vessel to connect to the CMA network. A disconnected user is seen as a merchant ship, hospital ship or any vessel not currently connected to the CMA network. This project's proposed deployable system facilitates information sharing for disconnected vessels in support of humanitarian efforts worldwide.

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ABSTRACT

After the attacks of 9/11, increased security became a national priority that resulted in a focus on National Maritime Security. Maritime Domain Awareness (MDA) is an initiative developed by the Coast Guard, in partnership with the U.S. Navy and other agencies to increase awareness in the maritime domain in support of maritime security [Morgan and Wimmer, 2005].

The purpose of MDA is to generate actionable intelligence obtained via the collection, fusion and dissemination of information from U.S. joint forces, U.S. government agencies, international coalition partners and commercial entities. This actionable intelligence is the cornerstone of successful counterterrorist and maritime law enforcement operations and is critical to Maritime Security [Morgan and Wimmer, 2005].

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EXECUTIVE SUMMARY

After the attacks of 9/11, increased security became a national priority that resulted in a focus on National Maritime Security. Maritime Domain Awareness is an initiative developed by the Coast Guard, to increase awareness of activities in the maritime domain in support of maritime security [Morgan and Wimmer, 2005]. The purpose of MDA is to generate actionable intelligence obtained via the collection, fusion and dissemination of information from United States (U.S.) joint forces, U.S. government agencies, international coalition partners and commercial entities. This actionable intelligence is viewed as the cornerstone of successful counterterrorist and maritime law enforcement operations and is critical to Maritime Security [Morgan and Wimmer, 2005].

The U.S. Navy has tasked its subordinate commands to identify and define capabilities to support this program. One such effort is the Comprehensive Maritime Awareness (CMA) Joint Capabilities Technology Demonstration (JCTD) [CMA Architecture Team, 2007].

This extending Comprehensive Maritime Awareness (xCMA) project augments the CMA JCTD by addressing the requirements and functions required to connect the user vessel into the CMA network. These vessels will hereafter be referred to as disconnected vessels, or Node 5's, where detailed definitions of Node 5's will follow in this report.

Using a tailored system engineering process, identified in detail in the following report, system alternatives were developed and evaluated based on stakeholder defined key system parameters. Four primary alternatives were recommended and evaluated based on reliability and throughput simulations resulting in a recommendation.

The resulting recommendation indicates all four options are viable systems and are capable of providing a solution to the problem; however, as this report shows, the Satellite Communication (SATCOM) with a Single Board Computer (SBC) alternative, is the higher ranked configuration for extending CMA to a disconnected node in support of humanitarian efforts. In this approach, a SATCOM capability is used as the communications means for connecting to the CMA network. The information from the

host system consisting of an SBC, modem/router, power supply, display, and input devices packaged in a ruggedized, transportable container is routed through the modulator demodulator (modem) and then transmitted by the satellite transmitter to the Node 4 satellite receiver (Node 4 details are to follow). The information from Node 4 is transmitted by a satellite transmitter and received by the system satellite receiver and demodulated for processing by the host system. The Network Interface Card (NIC) provides the system with a unique hardware Media Access Control (MAC) address for system identification. A Commercial-Off-The-Shelf (COTS) Global Positioning System (GPS) receiver is used to provide system Position Location Information (PLI). This recommendation provides a solution to enable the connection of a disconnected vessel to the CMA network.

I. INTRODUCTION

The evolving need for distributed information in support of national maritime security policies has given rise to the concept of Maritime Domain Awareness (MDA). The need for distributed information has been addressed at the National, Department of Defense and U.S. Navy levels. A Joint Capabilities Technology Demonstration (JCTD) effort titled Comprehensive Maritime Awareness (CMA) began in 2006 and intends to improve MDA through the demonstration of interagency and international information exchange. The focus of this engineering study is to augment the CMA JCTD efforts by defining the functional requirements, architecture, and systems required to extend CMA to disconnected users and vessels. The results include a recommendation based on the evaluation performed using a tailored systems engineering development processes.

A. BACKGROUND

MDA is an initiative developed by the Coast Guard, in partnership with the U.S. Navy and other agencies to increase awareness of activities in the maritime domain in support of maritime security [Morgan and Wimmer, 2005]. It evolved as a result of the threat and security challenges incurred in the Post 9/11 Era and was mandated by President George W. Bush in 2004 [White House, 2004].

The purpose of MDA is to generate actionable intelligence obtained via the collection, fusion, and dissemination of information from U.S. joint forces, U.S. government agencies, international coalition partners and commercial entities. This actionable intelligence is viewed as the cornerstone of successful counterterrorist and maritime law enforcement operations and is critical to Maritime Security [Morgan and Wimmer, 2005].

MDA is the result of the proper integration of a diverse set of capabilities, which provide decision makers with an effective understanding of the maritime domain. This effective understanding supports the decision making process and facilitates operational response. Achieving MDA depends on the ability to persistently monitor the four MDA

pillars (vessels, cargo, personnel and infrastructure), and scrutinize activities in day-to-day operations in such a way that trends and anomalies can be identified.

The CMA JCTD intends to demonstrate the effective and efficient use of data management strategies and automated tools. The goals of the CMA JCTD are to address the identified gaps with effective and efficient prioritization of maritime threats and to enable proper allocation of security resources in the maritime environment. Residuals of the CMA JCTD include, but are not limited to, an architectural structure, concept of operations, core collaborative toolsets and technology evaluation.

A gap in this implementation is the capability to connect a non-CMA vessel or entity to the CMA environment. This capability gap is the focus of this project effort, which defines the architecture, system requirements, and effort needed to facilitate the extension of CMA (xCMA) to disconnected vessels and users. The effort addresses the capabilities and capacities required to provide timely and accurate maritime situational awareness, in the form of their User Defined Awareness Picture (UDAP), to the disconnected nodes.

B. PROBLEM STATEMENT

The Chief of Naval Operations (CNO) noted that the navies are not only important in the execution of operations in support of wartime efforts, but are also "instruments of peace" and stressed the need for a global network of maritime nations. This network provides a collective response to all participants enabling a global perspective of the maritime domain that is essential for national security, global stability, and economic prosperity [Green, 2007].

This global network does not currently exist and addressing a suitable network is the primary goal of the CMA JCTD currently ongoing under the direction of Program Executive Officer, Command, Control, Communications, Computers, Intelligence (PEO-C4I). This thesis augments the work being completed by the CMA activities to facilitate continued information sharing. The specific focus is on the evaluation of the CMA architecture and the identification of modifications and systems required to ensure that disconnected vessels are active participants in CMA.

C. KEY TERMS AND DEFINITIONS

The definition of key terms is essential to understanding the scope of this effort. The intent of the following paragraphs is to identify these definitions as they pertain to this effort.

1. Comprehensive Maritime Awareness

CMA is an MDA implementation with a goal of addressing serious gaps in the ability to identify and prioritize maritime threats. The CMA architecture consists of three categories of nodes: user, operational, and enterprise. The CMA efforts have been focused on the requirements and implementation of the operational and enterprise nodes, depicted in the Operational View (OV-1) as Nodes 1-4, as shown in Figure 1. The user node, Node 5, has had limited evaluation to date and is being addressed by this thesis to augment the parallel efforts of the CMA JCTD.

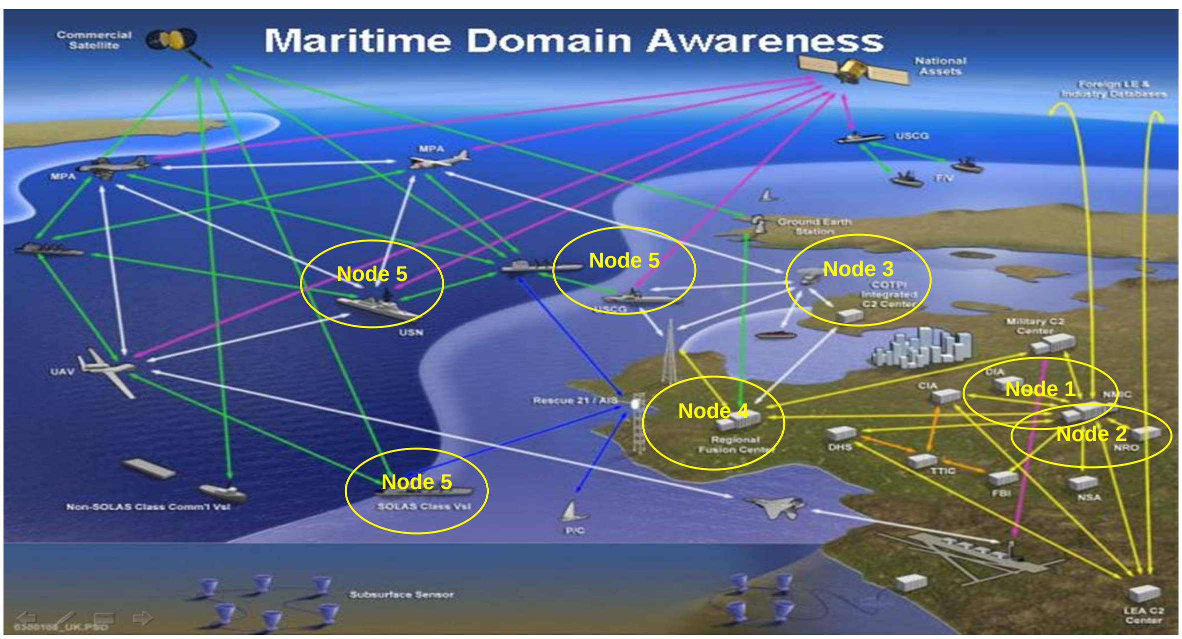

Figure 1. Comprehensive Maritime Awareness Operational View (OV-1). Source: CMA JCTD Interim Report on Architecture draft version 0.2 (2007) by David R. Reading [Reading, 2007]. This OV-1 provides a pictorial representation of the connections and node interactions as referenced in the CMA Architecture.

Nodes 1 and 2 are the primary and secondary nodes, with Node 1 functioning as the central repository, and Node 2 as the replication backup. Nodes 3 and 4 are regional

nodes, with Node 3's functioning as the geographically defined regional gateways and Node 4's as the sectional/functional gateways. The last node is the user node, which is identified as Node 5. The task of this thesis is to evaluate the effort needed to extend the CMA architecture to a disconnected Node 5.

The Node Connectivity (OV-2), as shown in figure 2, is a graphical representation of the relationship between the various CMA nodes. The primary focus for this engineering study, as indicated by the circle on figure 2, is in the relationship between the disconnected Node 5 and the existing Node 4. This narrows the focus and identifies the functional requirements and capabilities for a Node 5 vessel or user to be able to collaborate, define local UDAP, assess threats and submit maritime data/information to the Node 4 Gateway.

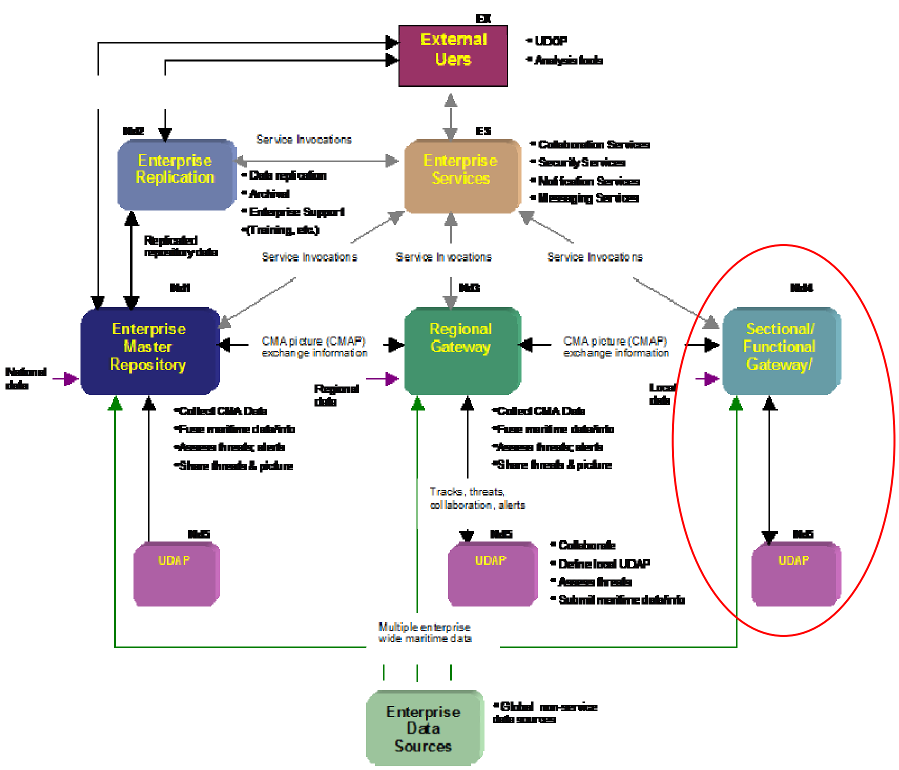

Figure 2. CMA Node Connectivity Diagram (OV-2).
Source: CMA JCTD Interim Report on Architecture draft version 0.2 (2007) by David R. Reading [Reading, 2007]. This figure depicts an abstract model of the CMA nodes. The circle on the figure identifies the primary focus of this thesis as the relationship between the disconnected Node 5 and existing Node 4 interaction.

2. Node 4

A Node 4 participant is the gateway between the Node 5 entity and the CMA network. It provides connectivity between Node 5 and all other CMA nodes. Node 4 is capable of:

- Collecting CMA data, including data from Node 5 and providing it to the CMA network
- Fusing CMA and Node 5 maritime data/info, using existing CMA fusion capabilities
- Assessing threats; alerts
- Sharing threats & pictures; including providing the UDAP for Node 5

3. Node 5

A Node 5 participant is a disconnected user or vessel that does not have direct connection to the existing CMA network. There is no data fusion capability at Node 5. This node is limited to sending request for area information and receiving updates from Node 4. The key functional areas addressed by a Node 5 entity include:

- Limited sensor data manually entered at an aperiodic rate
- Provides input into CMA network via Node 4 connection
- Receives guidance from CMA network regarding mission specific information via Node 4

D. ASSUMPTIONS

The following are the high level assumptions made during this evaluation effort.

- CMA exists, policies and restrictions are in place, and Nodes 1 through 4 are implemented and fully operational.
- Node 4 has fusion and operational capabilities to enable disadvantaged node connection to the CMA.
- The architecture is an open design to accommodate integration of other systems.

- Technology and policy for information sharing, e.g., Multi-Level Security (MLS) and UDAP, exist and are implemented.

E. OBJECTIVES

The direction provided by the primary stakeholders in the form of a Statement of Work (SOW), encompasses four primary objectives: (1) Characterization of the Problem Space, (2) Functional Representation and Decomposition, (3) Analysis of Key Capabilities, and (4) Documentation. The specifics of each of these areas, as defined by the SOW, are as follows:

1. **Characterization of the Problem Space**: identify current system and legacy deficiencies as well as constraints inherent in the operational environment in order to characterize, understand and bound the problem space. The project team identifies and translates the relevant CMA functions from the Fleet MDA Concept of Operations (CONOPS), National MDA CONOPS, and the CMA CONOPS into system engineering structures ("to be" concepts, data models, and architecture functions, requirements, solutions) necessary to develop the disconnected Node 5 concept. The project team evaluates the functions, requirements and architectures in support of the integration of CMA requirements.

2. **Functional Representation And Decomposition**: represent the system concepts through functional description and decomposition as well as system architecting and simulation. Develop representations, models, and methods to express automated resource collaboration concepts and information sharing solutions in the context of the CMA architecture and domains. The project team will develop a system model and architecture to evaluate the performance of the proposed architecture. System architectures are organized into views consistent with the Department of Defense Architecture Framework (DoDAF).

3. **Analysis of Key Capabilities**: the identification and evaluation of technologies and research areas is key to the integration of Node 5 into the CMA concept.

4. **Documentation:**
   a. **PROJECT REPORT –** Includes Chapters 1-5 detailing the problem statement, needs analysis and requirements definition, value system design, design and analysis and recommendations.
   b. **IN PROGRESS REVIEW (IPR) –** Status review provided end of Quarter 2.
   c. **FINAL PRESENTATION**

F. THESIS SUMMARY

In the past three years, the concept of MDA has evolved from the idea generated in the form of a presidential directive, to Concept of Operations, to the inception of a technology demonstration. There are several documents and plans that have been written detailing the requirements, operational impacts and draft architecture. One area overlooked to date is the introduction of a non-CMA, disconnected vessel, i.e. a hospital ship or shipping vessel, into the MDA environment and enable it to be an active participant in the information exchange. This is the focus of the thesis, the extension of CMA to disconnected users or vessels.

The basis for the processes implemented in the evaluation of this engineering task is a tailored systems engineering design process. This process was tailored to address the efforts required to perform the analysis and evaluation of the extended CMA (xCMA) project. The tailored process is shown in Figure 3. As depicted by the process flow, there are four main phases encompassing the engineering cycle; Needs Analysis & Requirements Definition, Value System Design, Design and Analysis, and Decision Making.

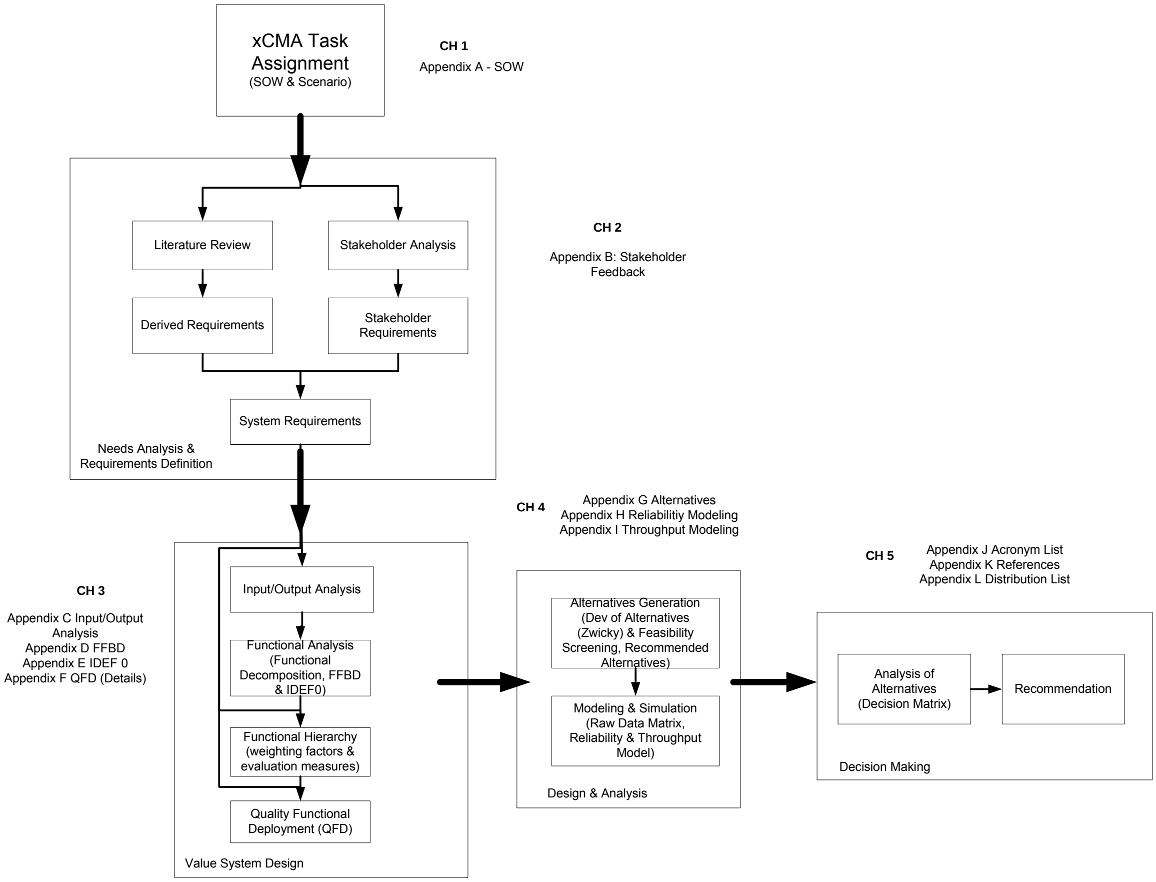

Figure 3. xCMA Engineering Process. This figure depicts the tailored systems engineering process used in this effort as well as the flow of this report.

These engineering processes provide guidance and facilitate the engineering activities necessary to define the problem, perform design and analysis and support decision making. These efforts culminate in an analysis of alternatives and a recommendation focused on the extension of CMA to a disconnected vessel.

The resulting recommendation indicates the Satellite Communications (SATCOM)-Single Board Computer (SBC) Alternative, as the preferred option for extending CMA to a disconnected node in support of humanitarian efforts. A satellite communications capability is used as the communications means for connecting to the CMA network. The information from the host system consisting of an SBC, modem/router, power supply, display, and input devices packaged in a ruggedized, transportable container is routed through the modulator demodulator (modem) and then transmitted by the satellite transmitter to the Node 4 satellite receiver. The information

from Node 4 is transmitted by a satellite transmitter and received by the system satellite receiver and demodulated for processing by the host system Mobile Terminal Equipment (MTE). The Network Interface Card (NIC) provides the system with a unique hardware Media Access Control (MAC) address for system identification. A Commercial-Off-The-Shelf (COTS) Global Positioning System (GPS) receiver is used to provide system Position Location Information (PLI).

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II. NEEDS ANALYSIS AND REQUIREMENTS DEFINITION

The first phase of the systems engineering process is the problem definition phase consisting of needs analysis and requirements definition. These efforts include literature review and stakeholder analyses and result in the generation of system level requirements consisting of derived and stakeholder requirements. See Figure 4 for a detailed illustration. The purpose of these activities are to accurately identify the problem, understand what the user wants and define value rankings of the system based on the user inputs. The problem definition phase begins with a primitive need statement. For this effort, the primitive need was derived from a combination of the Statement of Work and direction received from the stakeholders. The primitive need statement is as follows:

> "*To facilitate Maritime Domain Awareness, disconnected nodes need to be integrated into the Comprehensive Maritime Awareness construct to share data in support of humanitarian operations*".

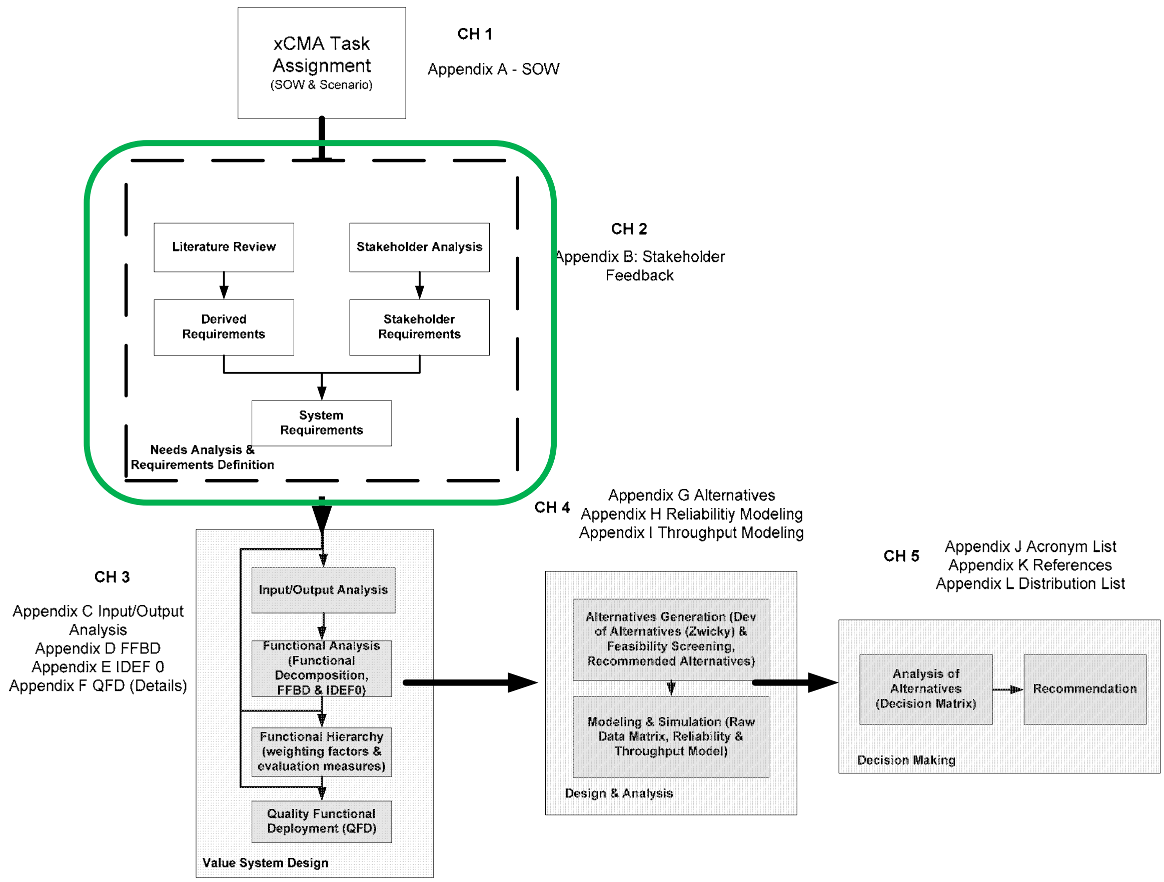

Figure 4. Needs Analysis and Requirements Definition Phase.
The green square in the figure indicates the current position in the tailored engineering process.

A. LITERATURE REVIEW

In order to ensure a clear understanding of the problem and the evolution of MDA, an extensive literature search was required. This literature search includes, but was not limited to, information relating to MDA and CMA. The tight coupling of this engineering task, with the on-going CMA efforts, resulted in stakeholder identification of the key documents pertaining to CMA. This chapter identifies the evolution of the documents, provides a summary of each document and details the accomplishments and capability gaps.

President George W. Bush's 2004 presidential directive began an initiative to increase awareness of maritime domain activities. Achieving MDA helps ensure national maritime security and supports an open global economy, which depends heavily on

maritime commerce. To maintain operation of the maritime commerce and provide maritime security, "MDA depends upon unparalleled information sharing" [United States Department of Homeland Security, 2005].

MDA has evolved and been shaped by documents generated at the National, Department of Defense and the U.S. Navy levels. These documents represent the work products and activities that have immediate impact on the U.S. Navy's effort to achieve MDA and include the National MDA CONOPS, Navy MDA Concept, Fleet MDA CONOPS, Navy MDA Architecture, Maritime Headquarters (MHQ) with Maritime Operations Center (MOC), CMA CONOPS and the CMA JCTD - Interim Report on Architecture. The interrelationships between these documents are illustrated in Figure 5.

The initial efforts in defining MDA are contained in two presidential directives, the National Security Presidential Directive (NSPD) 41 and the Homeland Security Presidential Directive (HSPD) 13. Since their creation, there have been several activities at the National and Department of Defense (DOD) levels initiating U.S. Navy efforts in MDA. The U.S. Navy's activities and work products were derived or influenced by visions, strategies, and plans from the National and DOD levels.

The National Policy HSPD 14 generated the National Strategy for Maritime Security. From this directive, the National Plan to Achieve MDA and the National MDA CONOPS were generated. The National MDA CONOPS further drilled into the implementation perspective and eventually created the MDA Information Technology Investment Strategy Capabilities Based Assessment (CBA) Process [United States Navy, 2007].

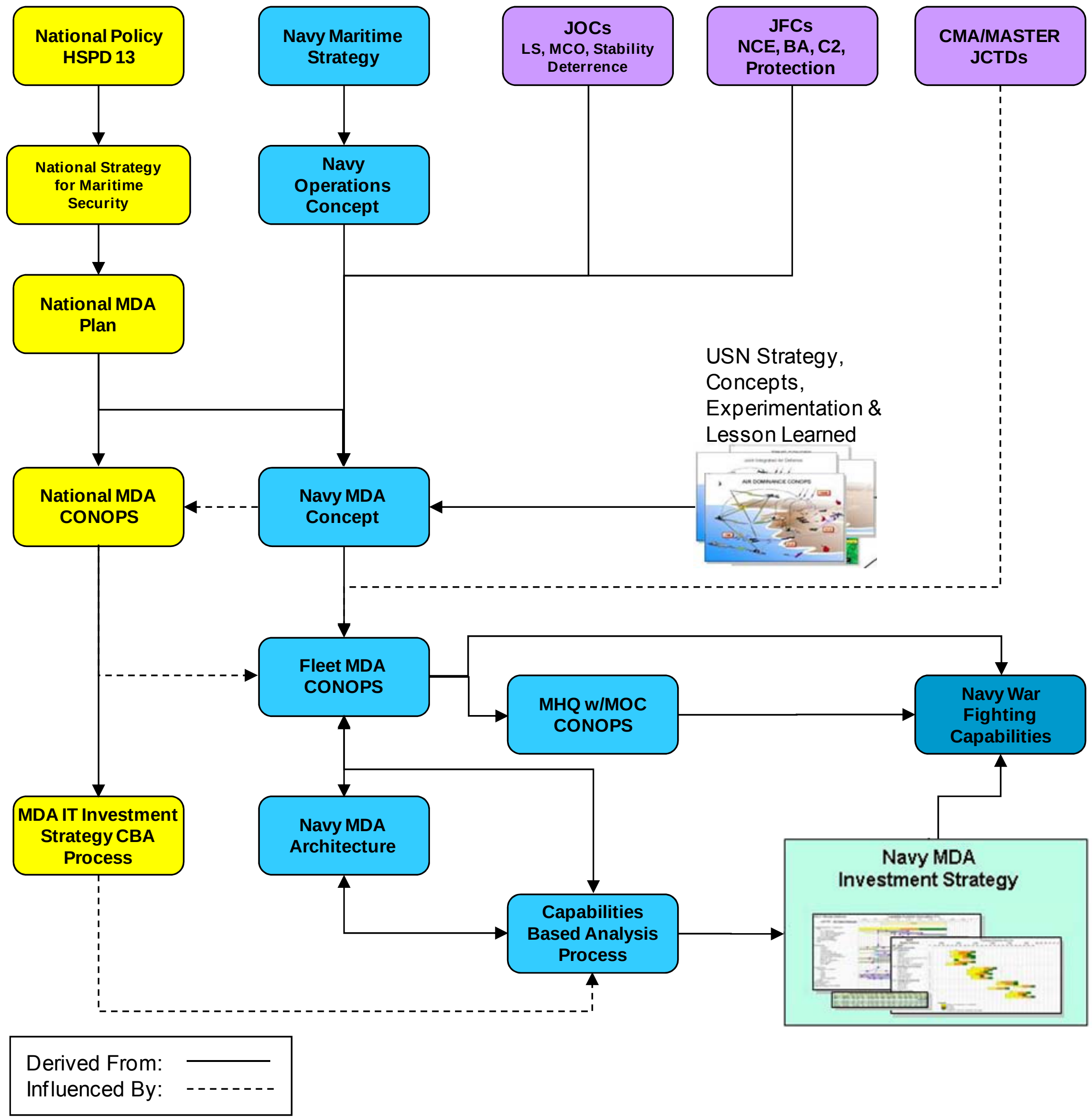

Figure 5. U.S. Navy Development Flow.
This figure shows the relationship between the U.S. Navy MDA documents. The dashed lines indicate the influential sources and the solid lines identify the originating documents. The yellow boxes represent the national documents. The blue boxes represent the U.S. Navy documents. The purple boxes represent the joint documents.

The definition of MDA is "the effective understanding of anything associated with the global maritime domain that could impact the security, safety, economy, or environment" [United States Department of Homeland Security, 2005]. The maritime domain is defined as "all areas and things of, on, under, relating to, adjacent to, or bordering on a sea, ocean or other navigable waterway, including all maritime-related

activities, infrastructure, people, cargo, and vessels and other conveyances" [United States Department of Homeland Security, 2005].

At the DOD level, there are two primary documents, the Homeland Security, Major Combat Operation and Stability Deterrence and the National Command Element Protection. These documents were created by the Joint Operations Center (JOC) and the Joint Forces Command (JFC) [United States Navy, 2007].

With the visions, strategies, and plans from the National and DOD levels, the U.S. Navy has developed several documents that include the Navy Maritime Strategy, Navy Operations Concept, Navy MDA Concept, Fleet MDA CONOPS, Navy MDA Architecture, Capabilities Based Analysis Process, Navy MDA Investment Strategy, and Navy War Fighting Capabilities [United States Navy, 2007]. In addition, the CMA JCTD documents resulting from the technology demonstration efforts provided clarifying information to the Fleet MDA CONOPS.

A synopsis of the core documents and the key information they contain are detailed below.

1. Navy MDA Concept

The NSPD 41 / HSPD (late 2004) directed the creation of the Maritime Security Policy Coordinating Committee (MSPCC) to oversee the development of the National Strategy for Maritime Security (NSMS). The MSPCC established the MDA Implementation Team to develop an interagency concept of operations and an interagency investment strategy. The conclusions are as follows;

- Homeland security was heavily focused on internal U.S. government information and intelligence sharing
- An international and interagency framework for maritime security would be required
- The U.S. Navy must play a key role

The U.S. Navy MDA Concept recognized that achieving MDA requires collaboration among the different stakeholders. The U.S. recognized that achieving MDA requires an understanding of our international partners. That is, the U.S. must understand and acknowledge that international partners are focused on how to support legal activities, such as freedom of the seas, domestic / commercial security, energy security, and fisheries, as well as how to deter illegal activities, such as narco-trafficking, illegal immigration, piracy, smuggling, and environmental damage. On the home front, it must be recognized that both private sector and all levels of government agencies play an important role in the success of MDA. Supporting the needs and roles of each stakeholder allows all interested parties to work toward common objectives that foster a culture of trust and confidence to achieve MDA.

The Navy MDA Concept identified gaps that the U.S. Navy must fill both internally and internationally. Internally, it is recognized that the U.S. Navy has limited capability in the collection and fusion of data. It is also recognized that the U.S. Navy only has a common operating picture at a localized, classified, tactical level and has a limited capability to develop a coherent picture of small craft in the littoral area of interest. Internationally, the U.S. Navy recognizes it must also address the shortcomings that prevent the collection and sharing of information across boundaries.

The Federal Aviation Administration (FAA) / North American Aerospace Defense Command (NORAD) model is identified as a good case to help establish safety of flight and effect commercial efficiency across the world. There are two key attributes of this model that are of interest to the Navy MDA Concept;

- The FAA/NORAD process is unclassified, which allows the sharing of information freely across boundaries
- The FAA/NORAD model is not controlled by DOD

The model seeks support and collaboration from DOD, which allows common goals to be accomplished while increasing the model's capacity. The Navy MDA Concept relies on the FAA/NORAD model to help translate MDA requirements into reality. The unclassified data and information collection, correlation, and dissemination capability and capacity of the collaborating stakeholders enables the free flow of

information in support of collective security. This provides a strong incentive for additional partners to join in the MDA effort [United States Department of Homeland Security, 2007].

2. National MDA CONOPS

The National MDA CONOPS was developed to execute the National Plan to Achieve Maritime Domain Awareness. The goals of this CONOPS are to facilitate the deterrence and prevention of hostile or illegal acts within the maritime domain and to enhance safety, security, economy and protect the environment. To accomplish these goals, the CONOPS created the following objectives: (1) Describe the problem, (2) Describe the interagency desired state of MDA, (3) Improve MDA planning and execution at all levels and (4) Identify MDA-related functions and desired MDA-related capabilities [United States Navy, 2007].

The scope of the National MDA CONOPS includes the stakeholders from the U.S. Federal Agencies within the Global Maritime Community of Interest (GMCOI), state and local agencies, private sector and international partners. It was developed to complement existing programs and initiatives that affect the maritime security and it identified key components for achieving MDA. The Global Maritime Intelligence (GMI) and Global Maritime Situational Analysis (GMSA) are identified as two of these key components. MDA is achieved through effective and efficient integration of GMI and GMSA (MDA = GMI + GMSA). To do so, the CONOPS recognizes the importance of the following;

- Distinction of responsibilities of the maritime agencies developing GMI and the responsibilities of those maritime stakeholders providing GMSA
- Interactive qualities of GMI and GMSA repeated throughout the CONOPS to emphasize the foundational dependence upon this partnership
- Synergy between intelligence and situational awareness

The following are defined in response to the CONOPS objectives in an effort to meet the goals listed above.

a. Problem Description:

Intelligence and information are critical to the success of MDA and must be gathered and shared across numerous boundaries for the effective understanding of the maritime domain. There are obstacles that impede the ability to share intelligence and information that are necessary to achieve MDA. The National MDA CONOPS identifies these obstacles as follows [United States Navy, 2007];

- Ineffective database connections for analysis of information gaps or redundancies
- Inability to create situational awareness due to ineffective area-target information fusion
- Incompatible and proprietary operating systems and organizations
- Lack of trusted partnerships for sharing of information and intelligence
- Policy restrictions on sharing data due to organizational perception
- Limited interagency communications, connectivity, and interoperability
- Limited interagency awareness of complementary mission

b. Interagency Desired State of MDA

The National MDA CONOPS envisions "an environment where federal, state, local, tribal, private sector and international partners embrace and achieve the common objective of obtaining and sharing information as a mechanism to increase safety, security and economic prosperity in the maritime domain and have the supporting architecture to do so" [United States Navy, 2007]. To reach this desired state, the MDA

environment depends on the ability to monitor activities; identify and detect anomalies; collect, fuse, and analyze data through the use of automated fusion and analysis tools. It also allows the operational decision makers to effectively engage and defeat anticipated threats and meet the MDA Essential Task List from the MDA Plan.

c. Improve MDA Planning and Execution [United States Navy, 2007]

The National MDA CONOPS addressed the processes required to achieve the desired MDA state. These processes included collection, fusion, analysis and understanding of data, dissemination, and archiving and maintaining discoverable information. Improving planning and execution in order to achieve the desired MDA state at all levels involves the implementation and adherence to these processes. The collection process involves gathering data and information from any pertinent source and method and requires cooperation between stakeholders of GMI and GMSA. The fusion process was defined as the activity of association, combination, and conversion of data or information into useable knowledge for the decision maker. This process was defined as critical when data or information examination was required for the detection of activities of interest with respect to operating patterns, anomalies, capability, and intent. The dissemination process was defined as "providing the right information to the right users" [United States Navy, 2007]. In the context of MDA, the dissemination process must provide relevant data, products, alerts, and warnings to the decision makers, analysts, and responders within the GMCOI. The archival and maintenance of MDA data and information was identified as essential for an effective MDA. Retention and retrieval of historic data was identified as a critical link for continuity of data and information used for enhanced operational capability.

d. Parsing the Domain [United States Navy, 2007]

The National Plan to Achieve MDA identified a requirement to "persistently monitor vessels and craft, cargo, vessel crews and passengers, and all identified areas of interest in the global maritime domain" [United States Navy, 2007].

This desired operational state identified a requirement for extensive resources. To maximize the limited resources, the CONOPS envisioned an ability to divide and organize the maritime domain in such a way that allowed the prioritization of assigned resources. An analysis of the complete supply chain of events was identified as a way to gain a better understanding of area of interest.

e. Levels of Awareness

The National MDA CONOPS determined the prioritization of MDA capabilities and needs required parsing the MDA domain and establishing the level of awareness for each Area of Interest (AOI), its associated processes, and its subject category [United States Navy, 2007]. The levels of awareness were categorized into general (level 3), specific (level 2), and detailed (level 1). The general level of awareness contained generalized knowledge of patterns of migration, travel, and work in the maritime domain. The specific level of awareness included specific platforms, their operators, and companies working in the area of interest. The detailed level of awareness included actual information at an individual level. This covered the individual passenger, crew, and worker area of interest [United States Navy, 2007].

f. Information Architecture

The National MDA CONOPS called for a net-centric architecture robust enough to provide the required environment for secure, collaborative, information-sharing. The CONOPS envisioned an information architecture that allowed data providers to expose data for consumers to locate and retrieve. Furthermore, the data was expected to flow through the enterprise's multi-level protocols and classifications with automated sanitization. The ultimate desired state of the user was identified as the ability to create a User Defined Operational Picture (UDOP) via a Services-Oriented Architecture (SOA) [United States Navy, 2007].

3. Concept of Operations for Fleet Maritime Domain Awareness (Fleet MDA CONOPS)

The Fleet MDA CONOPS was developed by the U.S. Navy and approved for use on 13 March 2007 [United States Navy, 2007]. It provided a foundation for the U.S. Navy commanders to build and achieve MDA. This foundation provided the necessary background to understand the fleet's role in MDA and how it related to other entities including the U.S. Navy and interagency programs and directives. The Fleet MDA CONOPS focused primarily on the operational level of warfare [United States Navy, 2007].

The Fleet MDA CONOPS defined MDA one level down from the Navy MDA Concepts and National MDA CONOPS, integrated standardized MDA-related processes and mechanisms into Fleet operations and guided the development of a U.S. Navy architecture supporting MDA. This Fleet MDA CONOPS was intended to help the U.S. Navy in fulfilling its roles and responsibilities as directed in the National Strategy for Maritime Security and its supporting plans" [United States Navy, 2007].

The Fleet MDA CONOPS addressed how MDA was enabled by the use of maritime intelligence as envisioned by the Global Maritime Intelligence Integration (GMII) Plan and the National Strategy for Maritime Security. It also stated that effective decision making is the result of an enabled MDA environment in accordance with the Maritime Operational Threat Response Plan (MOTR) and in support of all U.S. Navy missions" [United States Navy, 2007].

The primary purpose of the Fleet MDA CONOPS was to provide the fleet with an understanding of MDA and to describe the processes and mechanisms that enabled the U.S. Navy to accomplish missions. The CONOPS served as a basis for future U.S. Navy capability investment decisions, and influenced MDA development to meet current and future U.S. Navy needs. The following sections list the capability gaps, assumptions, restraints and constraints, operating environment, MDA fleet deployment and tasks and Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel, and Facilities (DOTMLPF) items identified in this document.

a. Warfighting Capability Gaps

The following user inputs were used to derive the warfighting capability gaps [United States Navy, 2007]:

- Lack of net assessment, fusion, and collaboration tools
- Lack of cross domain solutions for information sharing
- Lack of maritime information gathering and collection within U.S. Navy areas of interest
- Lack of communication system training

b. Assumptions and Constraints

The Fleet MDA CONOPS addressed the assumptions, restraints, and constraints to ensure that there was an understanding within the U.S. Navy MDA organization. The assumptions included the following [United States Navy, 2007]:

- The National CONOPS for MDA will be approved
- The Navy MDA concept will be approved
- MHQ w/MOC will exist as the principal operational-level command and control node for the U.S. Navy
- MHQ w/MOC will be the primary operational-level net assessment center for MDA within the U.S. Navy
- The National Maritime Intelligence Center (NMIC) will serve as the Center Of Excellence (COE) for all-source maritime intelligence fusion within the GMCOI
- Technology and National DOD policy for information sharing, e.g., MLS and UDOP, will be developed and implemented within the Future Years Defense Program (FYDP) to support fleet information sharing requirements

- The MDA data strategy Community Of Interest (COI) will develop common data standards for MDA information to be shared across multiple security levels and network enclaves
- Engagement with US, allied, and partner nations, Other Government Agencies, Non-Governmental Organizations, and private industry is necessary to develop MDA

The restraints identified the scope of the U.S. Navy's contribution. The U.S. Navy supported initiatives for expanded reporting requirements for vessels and cargo. It was governed by maritime strategy and was limited to areas where naval forces operate [United States Navy, 2007].

The constraints included the focus on U.S. Navy capabilities to be made available within Future Year's Development Program (~2014). The Fleet MDA CONOPS identifies U.S. Navy challenges to achieve MDA. These challenges included sharing of data and information within the global maritime domain, handling, analyzing, releasing, and disseminating data from multiple sources, operating in a low bandwidth environment, and adhering to different laws, policies, regulations, and guidance [United States Navy, 2007].

c. Operating Environment

The Fleet MDA CONOPS addressed two types of operational environments; the physical setting and the associated information classification layers. The physical setting covered the U.S. Navy's primary operational area, "blue water," and the less common environments such as "green water" (non-combatant evacuation operations) and, "brown water" (riverine operations) [United States 2007]. The information classification layers identified the U.S. Navy's focus on overcoming the challenges of operating in an environment with multiple collaborators and different levels of security access.

d. MDA Capability Deployment

A key focus of the Fleet MDA CONOPS was the MDA capability deployment. The CONOPS identified the U.S. Navy's contribution at three levels; (1) tactical, (2) operational, and (3) strategic. At the tactical level, the U.S. Navy collected and shared information. At the operational level, the U.S. Navy participated in creating a synergy between operations and intelligence to help create regional maritime situation awareness. At the strategic level, the Office of Naval Intelligence collaborated with the larger GMCOI Intelligence Enterprise to develop maritime intelligence and threat awareness [United States Navy, 2007].

The CONOPS identified five key information exchange ingredients for achieving MDA. These ingredients included: Location and Tracking Information, Contextual Information, Reference Information, Trend Analysis, and Intelligence [United States Navy, 2007]. It also addressed the integration of MDA requirements into existing or future systems and structures. Two key initiatives, Automatic Identification System (AIS) and Long Range Identification and Tracking (LRIT) system, incorporated important capabilities into the MDA. The AIS was identified as a maritime transponder for all vessels 300 gross tons or greater. The LRIT, mandated by the International Maritime Organization as part of the Safety of Life at Sea Convention, was identified as a requirement to provide the ship's identity and time stamped location [United States Navy, 2007].

e. Fleet MDA Tasks

To address the fleet MDA requirements, the Fleet MDA CONOPS derived a set of twelve tasks from the Universal Navy Task List. These tasks were applicable to the commanders at the strategic, operational, and tactical levels. The derived tasks were identified as follows [United States Navy, 2007]:

- Direct operational intelligence activities
- Process and exploit collected operational information

- Produce operational intelligence and prepare intelligence products
- Disseminate and integrate operational intelligence
- Evaluate intelligence activities in the joint operations area (JOA)
- Assess the operational situation
- Develop a shared understanding of the situation
- Acquire and communicate operational-level information and status
- Collect and share operational information
- Prepare plans and orders
- Command subordinate operational forces
- Coordinate and integrate joint/multinational and interagency cooperation

Along with the twelve tasks, the Fleet MDA CONOPS identified the responsible entities at each of the requirement levels. At the strategic level, NMIC was identified as responsible for conducting maritime intelligence activities, integrating and fusing enterprise intelligence, supporting the operational and tactical requirements in the maritime domain. At the operational level, the MHQ was identified as responsible for directing the operational intelligence activities and commanding assigned forces. The activities included "indications and warning, situational awareness, target development, collection management, all-source threat analysis, and assessment reporting for operational planning and execution" [United States Navy, 2007]. At the tactical level, Commander Task Forces, Commander Task Groups, and Commander Task Units were identified as responsible for directing the tactical and operational intelligence activities specific to mission and operations. The tasks included classification, identification, and engagement areas [United States Navy, 2007].

Along with the fleet MDA tasks and responsible entities, the Fleet MDA CONOPS identified "processes" as a key ingredient necessary for successful operational intelligence activities for MDA. The processes used in the MDA life cycle include five phases [United States Navy, 2007]:

- Intelligence planning and direction
- Collection

- Processing/Exploitation, i.e., process and exploit collected operational information
- Analysis/Production/Dissemination, i.e., produce operational intelligence and prepare intelligence products
- Assessment/Feedback, i.e., evaluate intelligence activities in the JOA

These phases are the foundation for day-to-day activities which ensures the maritime planning process mirrors the joint planning process, develops the MHQ commander's intent, turns it into an executable plan, and tasks tactical forces.

f. Validation Requirements

To address the validity of the MDA requirements, experiments, exercises, modeling and simulation (M&S), war gaming, workshops, seminars, and rock drills have been identified. To effectively prepare and conduct any requirements validation, the Fleet MDA CONOPS identified analytical questions that needed to be asked in order to gain relevant measures of effectiveness. Along with the analytical questions, the CONOPS also identified an analysis plan focused on workshops, wargames, and exercises. To effectively measure the analysis, the CONOPS identified Measures of Effectiveness (MOE) and Measures of Performance (MOP). In addition to the MOEs and MOPs, an Experimental Campaign Plan (ECP) was developed to help guide the requirements validation [United States Navy, 2007].

4. DOTMLPF

The Fleet MDA CONOPS also addressed the DOTMLPF implications. Under doctrine, due to the nature of MDA, the CONOPS identified a shift from an individual to an integrated operational environment. This requires a development of doctrine and policy that includes:

- Roles, Mission, and the GMSA task
- Enterprise hubs

- Information sharing policies
- Protocols with non-DOD partners
- Revised foreign disclosure policies to facilitate the time sensitive nature of maritime areas of interest

For the organizational focus, policies were required to help define and facilitate the inter-agency relationship among the members of the GMCOI. These included stakeholders at the local, state, regional, national, and international levels. For training, the CONOPS called for effective and efficient training at all levels which included individual skills, unit and composite group training. The training was identified to include live, virtual environment that involves real-world complexity in against a range of postulated threats. For the materiel solutions, alternatives are addressed to ensure effective future analysis. For the leadership area, the CONOPS identified a requirement to bring all stakeholders together to ensure trust, confidence, effective and efficient training, and lessons learned. For personnel, a detailed manpower assessment was required to effectively implement the Fleet MDA CONOPS. The CONOPS identified required training facilities for each participating organization. The CONOPS identified that there were no common operating processes, systems or linkages to the GMSA enterprise hubs. Therefore, each participating organization must use existing facilities to satisfy the MDA requirements for the near term [United States Navy, 2007].

5. CMA JCTD CONOPS

The CMA JCTD CONOPS was generated under the efforts of the CMA JCTD which was focused on improvement of MDA through the demonstration of interagency and international information exchange. The goals of the CONOPS were to address the identification gaps through the effective and efficient prioritization of maritime threats and to enable proper allocation of security resources in the maritime environment.

The U.S. Pacific Command (USPACOM) and Department of State (DoS) took steps in developing a multinational maritime security framework in March 2004. This collaboration resulted in a multilateral maritime security framework in the Asia-Pacific region. This effort was designed to offset risks posed by transnational threats including

"terrorism, trafficking in humans and drugs, movement of illicit cargo, and piracy" [CMA Architecture Team, 2007]. Partnering with willing nations moves the participating stakeholders toward MDA capability "through unity of effort to identify, monitor, and intercept transnational maritime threats consistent with existing international and domestic laws" [CMA Architecture Team, 2007].

To move one step closer to achieving MDA capability, the Republic of Singapore initiated a proposal for a joint effort with the U.S. to establish a CMA JCTD. This JCTD refines the goals and objectives identified in the National Strategy for Maritime Security, the GMII Plan, and the NSPD 41 / HSPD 13 Presidential Directive Security Policy [CMA Architecture Team, 2007].

In the summer of 2005, USPACOM, USNORTHCOM, and USEUCOM initiated a joint collaborative effort to develop the CMA JCTD capability. This JCTD was planned to accomplish MDA in three spirals. Spiral I focuses on the establishment of baseline information exchange in the coalition environment with stakeholder participation from the Republic of Singapore, USPACOM Pacific Fleet Command (COMPACFLT), and maritime analysts. Spiral II focuses on the internal U.S. interagency maritime information exchange and Spiral III focuses on implementing net-centric information management capability and demonstrating products relating to the MDA COI [CMA Architecture Team, 2007].

a. Operational Environment

Requirements have been established to integrate information from the DOD, U.S. Coast Guard, Coalition/Allied forces and commercial maritime entities. From these sources disparate, tracking and other types of informational data must be integrated into a UDAP, which can be tailored for situation awareness.

There were three operational concerns identified in maritime tracking. The concerns were as follows:

- An MLS *solution* must be identified for data sharing

- The warfighter’s systems do not have the capability required to integrate data from disparate sources
- There is no single organization that can effectively coordinate Continent United States (CONUS) and Global requirements necessary for MDA

The concerns regarding the integration of MDA are part of a larger problem the warfighters have with Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR). A requirement was identified to provide an MDA capability to automatically detect, track and identify any movement of vessels in the assigned area of responsibility. This information was identified as a support for Command and Control (C2) decision-making.

The gathered MDA information must be consolidated, disseminated and displayed in a tailored presentation. “The intent of CMA is to highlight threat information to maritime analysts as soon as possible, thereby increasing reaction time and providing greater opportunity to monitor and/or interdict these threats at greater distances” [United States Navy, 2007].

6. CMA JCTD-Interim Report on Architecture Version 0.2

The CMA JCTD Interim Report on Architecture was a key document summarizing the work done to date by the CMA Architecture team. This document not only outlined the work products that were currently available but also included a section that provided an assessment of the current architecture and the way ahead. The following is a synopsis of the processes, tools, architecture and implementation guidance detailed in this document.

a. CMA Business Processes

As a result of the second workshop seven CMA business processes have been defined. These processes were also modeled with the Universal Modeling Language (UML) 2.0. The business processes consist of the following:

- A User Defined Subscription

- First Hand Reporting
- Threat Identification and Prioritization
- Data/Information Sharing
- New Information Source or Capability Incorporation
- Security Auditing
- Continuous Improvement

b. Network Architecture

As discussed in the CMA JCTD CONOPS, CMA uses the Combined Enterprise Regional Information Exchange System (CENTRIXS) network structure to share information with international partners. The software was based on a SOA and utilized both collaboration and integration tool sets. CMA utilized existing networks with tailorable information flows to exchange information at the appropriate security levels.

c. CMA Core Collaborative Tool Sets

The CMA core collaborative tool sets included email, chat and web services. The DOD and Services Defense Planning Guidance identified these tool sets as "required technology". Other capabilities such as voice over Internet Protocol (IP) and video teleconference may be used in the future but are currently unavailable due to the bandwidth limitation of CENTRIXS. The CMA Enterprise Service also provided other services, which included mapping, notification, information assurance management, and authentication and authorization services.

B. DERIVED REQUIREMENTS

At the conclusion of the literature review, a list of requirements relevant to the extension of CMA was identified. Table 1 provides a consolidated listing of these requirements. Each requirement is listed beneath the document that it was derived from and given a reference number that is used in the traceability matrix discussed in the System Requirements discussion below.

Table 1. Derived Requirements

Document	
Reference Number	**Derived Requirement**
National CONOPS to Achieve Maritime Domain Awareness. The system shall:	
1.	Provide a secure, collaborative, information-sharing environment and unprecedented access to decision-quality information. A fundamental attribute of a net-centric environment is the ability for any consumer of information to get the information that is needed, when it is needed
2.	Provide pertinent data, products, alerts, and warnings to support decision makers, analysts, and responders within the GMCOI
3.	Provide the necessary level of awareness to the end-users for information about specific MDA pillars
4.	Provide a multi-level security and access structure as appropriate, tailored to enable users to pull appropriate information and data from the network, and to receive alerts and warnings pushed from the network to users
5.	Grant user access and provide data and services control based on roles, responsibilities and authorities within the multi-level security enterprise
6.	Provide a user defined awareness picture (UDAP). The UDAP will provide a shared display of friendly, enemy/suspect, and neutral tracks on a map with applicable geographically referenced overlays and data enhancements. The UDAP environment may include distributed data processing, data exchange, collaboration tools, and communications capabilities. The UDAP may include information relevant to the tactical and strategic level of command. This includes, but is not limited to, geographic information systems data, assets, activities and elements, planning data, readiness data, intelligence, reconnaissance and surveillance data, imagery, and environmental data

Document	
Reference Number	**Derived Requirement**
Fleet CONOPS for Maritime Domain Awareness. The system shall:	
7.	Provide flexible, scalable, and tailorable techniques, processes, and procedures that can be adapted rapidly and securely
8.	Provide reliable communications between, and among, nodes in the MDA network
9.	Implement a service oriented architecture (SOA) that will provide multi-level security, information assurance, storage, and performance management for a robust recovery capability. The architecture will allow appropriate information exchange transparency between non-classified, classified and unclassified domains, as well as across numerous contributing agencies. An SOA will enable the MOC and fleet units to publish and subscribe to common-source data in order to develop a common understanding through a UDAP. It is a picture of the current state of the maritime environment with available layers of information that includes information specific to the vessel such as history, destination, crew, cargo, affiliation, etc
10.	Provide effective and efficient training across the spectrum of activities from individual skills development, to unit and composite group training
CMA Implementing Directive (JROC Approved). The system shall:	
11.	Provide an SOA based operational capability to perform MDA functions
CMA CONOPS The system shall:	
12.	Provide the capability to rapidly assemble a theater wide maritime picture and disseminate selected track information to international and interagency partners through classified and unclassified networks using appropriate security guards

Document	
Reference Number	**Derived Requirement**
13.	Use, develop or modify the automated decision aid to display information in a UDAP environment and leverage service oriented architecture to manage data, enable data exchanges and provide CMA participants with the means to display data sets meeting their respective requirements
14.	Include e-mail, chat and web services as its core tools. Voice over IP (VoIP) and video teleconference capabilities are envisioned to be part of the CMA capability
15.	Develop a service oriented architecture that will fuse this information and integrate it with automated vessel tracking capabilities to develop a comprehensive maritime picture
16.	Provide an open-system architecture that facilitates accurate, timely and inter-operable information and intelligence sharing and promotes collaboration among the GMCOI
17.	Consolidate unclassified data for CMA through the use of local, commercial, and other readily available source information. Data, as appropriate, will be consolidated and passed to higher classified systems. Either of these can make the originally unclassified data classified. As such, this newly formatted data is passed through a Multi-Level Security Guard onto the appropriate servers and databases
18.	Provide depot level maintenance

Document	
Reference Number	**Derived Requirement**
19.	Provide security requirements will comply with those standards delineated in appropriate DoD Operational Security (OPSEC) Instructions. Security measures will support the five fundamental information assurance elements (confidentiality, integrity, availability, authentication, and non-repudiation) and will define how CMA manages, protects, and distributes sensitive information. System accreditation will be the responsibility of the Designated Approval Authority (DAA)
20.	Provide warfighters the capability to accurately display all available military and commercial maritime data on the UDAP
21.	Enhance the value of existing systems by allowing their Position Location Information (PLI) data to be displayed on the UDAP and providing a mechanism for multi-source correlation, providing increased situation awareness

Source: Documents identified by stakeholders as key to this thesis were reviewed and the derived requirements were compiled.

C. STAKEHOLDER ANALYSIS

Stakeholder Analysis was performed to determine and validate the people relevant to the problem, and to capture their requirements for the system. The stakeholders, or customers, have significant interest and/or investment in the problem and its solution. The primary customers for the xCMA effort were identified as the MDA Project Deputy and Transition Manager, PEO-C4I and his team. Mr. John M. Green and Dr. Rachel Goshorn, the advisors and coordinators for this effort, and were also identified as stakeholders. CMA was based on the MDA concepts and policies. Due to the primary focus for this effort being on CMA, the stakeholders were limited to those listed above to ensure that guidance received is directly applicable to the problem at hand.

Due to the parallel development efforts of the CMA JCTD, stakeholder inputs and communications were under the direction of Dr. Rachel Goshorn and consisted of limited interviews and email exchanges. The requirements received from the stakeholders were compiled and have been included in Table 2.

Table 2. Stakeholder Requirements

Document	
Reference Number	**Stakeholder Requirement**
Statement of Work. The system shall:	
22.	Extend Comprehensive Maritime Awareness (CMA) to disconnected nodes to facilitate continued information sharing
23.	Operate within the size, power and weight constraints similar to small vessels and assumes max distance to node 4 of 30 nm
Stakeholder Analysis. The system shall:	
24.	Handle a minimum Bandwidth of 128 Kbps

Source: Statement of Work and stakeholder feedback via interviews and email exchange established this list of stakeholder requirements.

D. SYSTEM REQUIREMENTS

The culmination of the Needs Analysis and Requirements Definition activities are the system requirements for the xCMA system. These are comprised of the derived requirements identified in the literature review activities and the stakeholder requirements provided by the stakeholder. These requirements are listed in Table 3.

Table 3. System Requirements

xCMA System Requirements						
Defining Documents	National CONOPS to Achieve Maritime Domain Awareness (1-6)	Fleet CONOPS for Maritime Domain Awareness (7-10)	CMA Implementing Directive (JROC Approved) (11)	CMA CONOPS (12-21)	SOW (22-23)	Stakeholder Communications (24)
Provide secure connection of Node 5 to CMA Node 4	1,4,5	8		19		
Provide unclassified warnings and alerts	2,4					
Provide unclassified UDAP	6	9		13,20		
Provide access to all required info	1,4,5					24
Provide access to web services				14		24
Provide capability to store data and info				13		
Provide intuitive human system interface	6	9		13,20		
Provide scalable system - maximize interoperability	6	7		13,24		
Provide flexible system - allow user display customization	6	7		13		
Provide accurate data and info	2,3			16, 20, 24		
Provide accurate local data and info	2			13,16,17,20		24
Provide a portable system					23	
Provide reliable system		8		18	22	
Provide flexible system operator training		10				
Minimum Bandwidth = 128 Kbps						24
Connect with CMA	1,4,5	8		19	22	
Receive data and information	1,2,3,4	8, 9	11	12,16,17,21	22	24
Transmit data and information		8,9	11	12,13,14,16	22	24
Manage data and information		9		13,19		
Provide unclassified collaboration	1,4,6	8,9		14,16		
Provide open architecture design		7		16		
Provide plug and play interface		7		16		
Provide Graphical User Interface (GUI)	6	9		13,20,21		
Provide Computer Based Training (CBT)		10				
Provide depot only maintenance paradigm				18		
Provide Ao = 0.9		8		18	22	
Provide MTBF = 1500 hrs		8		18	22	
Operating radius = 30 nautical miles					23	

Source: These xCMA requirements were pulled from key documents identified by the stakeholders. The left column is a list of all the requirements. The columns to the right each identifies a specific document. The numbers in each of these columns corresponds to a requirement.

III. VALUE SYSTEM DESIGN

The next phase in the tailored systems engineering process is value system design. This phase consisted of an Input/Output Analysis, Functional Analysis, Functional Hierarchy and Quality Functional Deployment (QFD) analysis. See Figure 6 for a detailed illustration. The purpose of this phase in the systems engineering process was to identify a set of objectives and evaluation measures. In addition, multi-dimensional attributes and decision criteria were developed to provide guidance during the remainder of the system engineering process and to ensure selection of the most appropriate system.

This phase begins with the identification of the input, output and functional requirements and functional interaction between Node 4 and Node 5. It then proceeds with the identification of objectives and evaluation measures in the form of a functional hierarchy. At this point an effective need statement was defined based on the needs analysis. Finally, QFD analysis was applied to promote integration of organizational functions and to facilitate responsiveness to the system and stakeholder requirements.

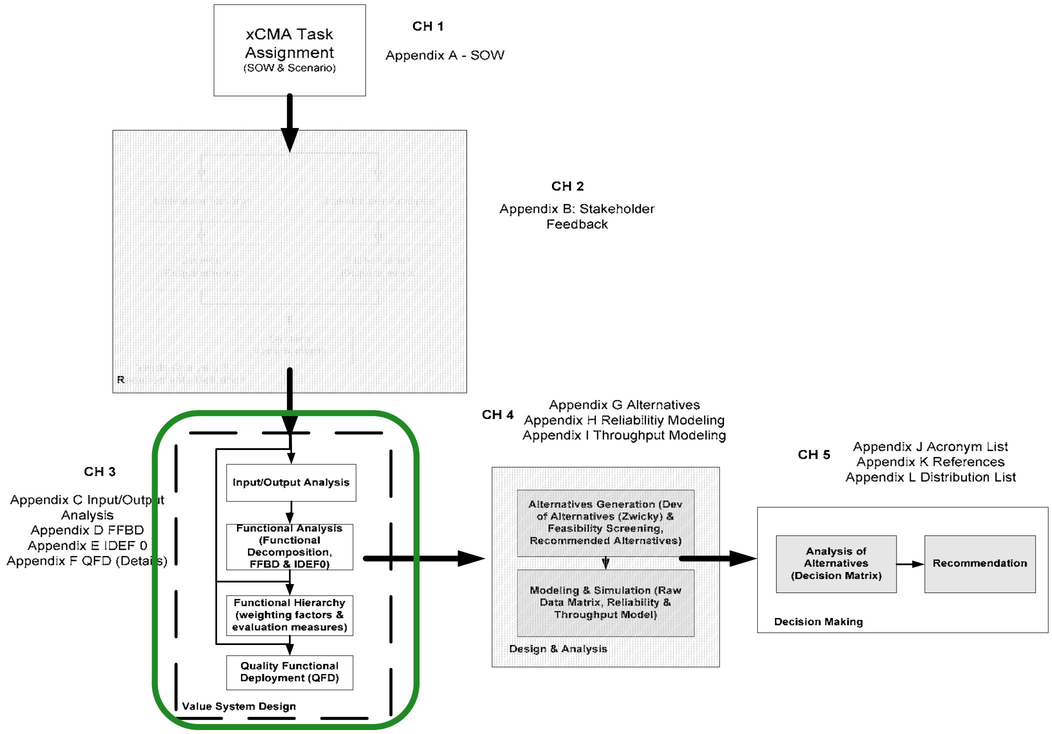

Figure 6. Value System Design Phase.
This drawing shows the relationship of the Value System Design Phase to the other activities in the system engineering process. The green square in the figure indicates the current position in the tailored engineering process.

A. INPUT-OUTPUT ANALYSIS

In addition to understanding the problem and the customer's needs, it was necessary to adequately determine the boundary conditions and scope of the problem. To facilitate this, the xCMA system was evaluated from a component and structural perspective. This resulted in the identification of two nodes of interest, the gateway node (Node 4) and the disconnected node (Node 5), as well as the overarching CMA Architecture. These are key elements in defining the core of the xCMA system and provided the boundaries and constraints under which it must function.

The scope of this effort is limited to a point-to-point connection between Node 4 and a disconnected Node 5. A system context diagram was generated detailing the inputs and outputs of the overall system and is shown in Figure 7.

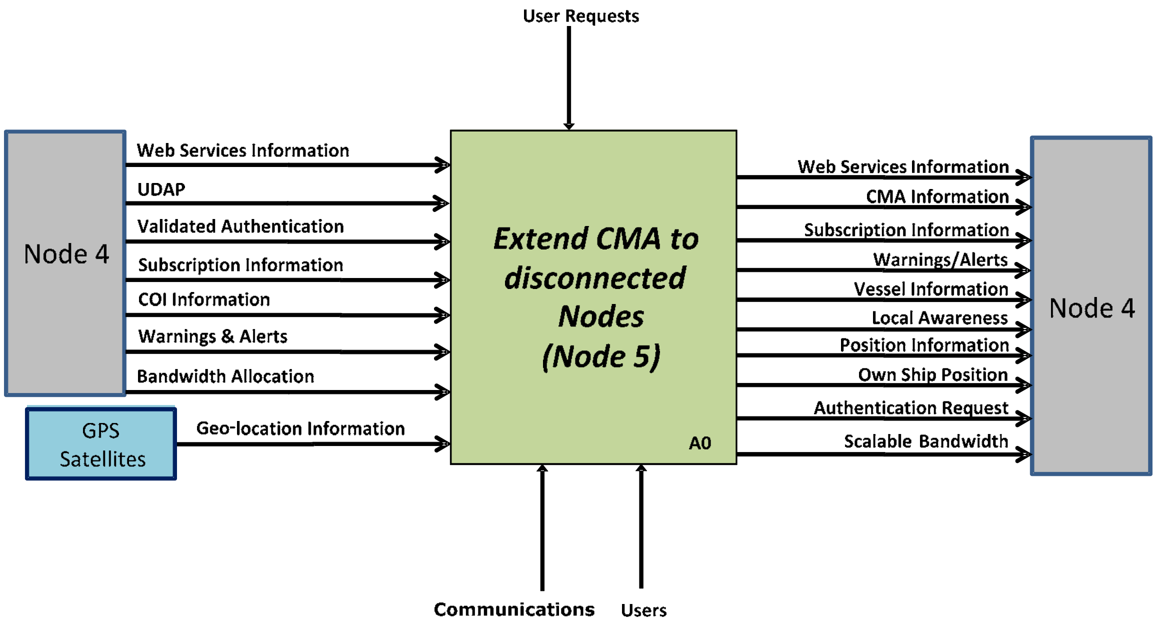

Figure 7. xCMA Context Diagram
This is the Context Diagram, from the Node 5 perspective, of the xCMA system. It depicts the information flow between the system and the Node 4 Gateway.

Definitions of the inputs/outputs of the xCMA system are shown in Figure 8, the Operational Node Connectivity. Each of the identified inputs and outputs are detailed below for clarification.

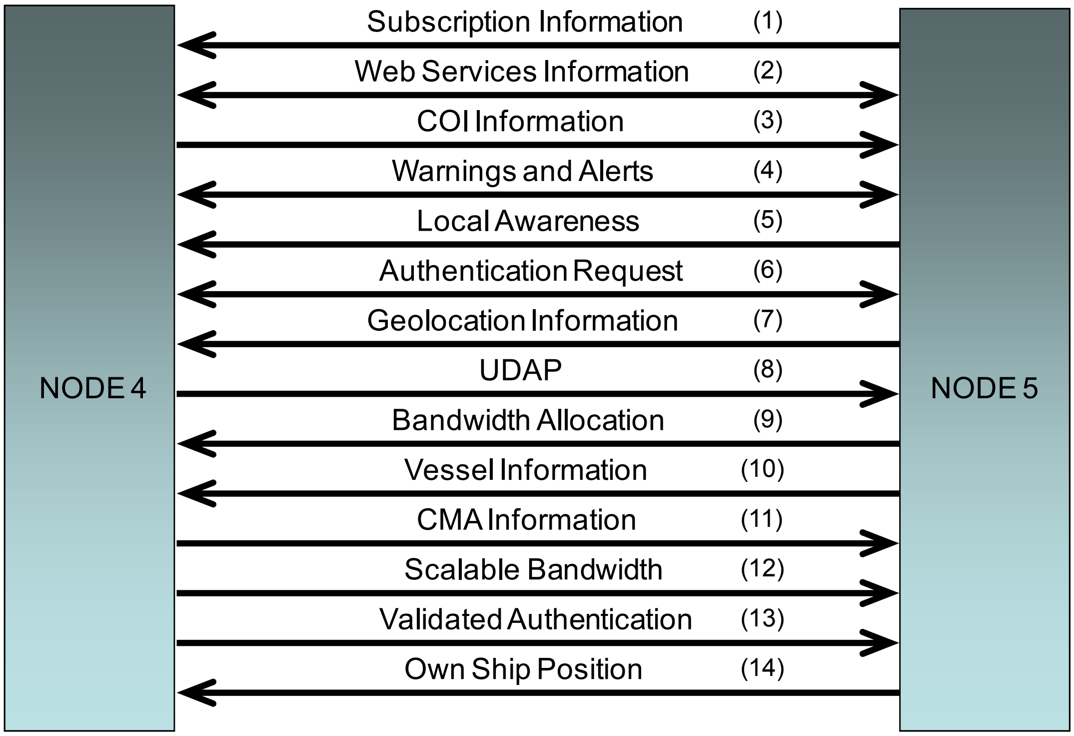

Figure 8. Operational Node Connectivity (OV-2).
This diagram details the input and output information and the directional flow from Node 4 and Node 5.

1. Subscription Information: Subscription Information defined as an input and output to the proposed system. The local Node 5 user enters relevant subscription information (input) based on the required data. The system sends the subscription information to Node 4 for processing (output).

2. Web Services Information: Web Services Information provides access to a web browser, chat functions, e-mail and collaboration tools for the disconnected Node 5. Web Services Information defined as both an input and output to the proposed system since the flow of information is bi-directional to and from Node 5.

3. COI Information: COI Information was defined as an input to the proposed system and was provided in the form of a web based data repository by Node 4. The proposed system has the capability to store and access this database locally with updates being provided through the Node 4 gateway.

4. Warnings & Alerts: Warnings and Alerts were defined as an input and output of the proposed system. The proposed system shall be capable of receiving Warnings and Alerts via Node 4 (input) to be provided to Node 5. Node 5 sends locally generated Warnings and Alerts (output) to Node 4 via the proposed system.

5. Local Awareness: Local Awareness was defined as an input and output to the proposed system and defined as being provided by Node 5. Node 5 inputs any Local Awareness it has from onboard sensors which will be provided to Node 4 (output).

6. Authentication Request: The Authentication Request was defined as an input to the proposed system and was tied to the system's physical location and Network Address. Some additional form of authentication was determined necessary to ensure the person accessing the CMA network was authorized to obtain CMA information. Additional authentication requirements were detailed in the Authentication Policy provided by the CMA architecture.

7. Geolocation Information: Geolocation was defined as the real-world geographic location of the connected system and an input to the proposed system. Geolocation Information provided automatically by the systems position location information capability.

8. UDAP: The UDAP was defined as an output of the proposed system. The UDAP was also defined as an output to a display on the xCMA system. The UDAP, sent by Node 4, is dependent on the own ship position information, vessel information and user requirement.

9. Bandwidth Allocation: Bandwidth Allocation was defined as an input to the proposed system and provided by Node 4. Allocation of bandwidth depends on the user requirements for information and urgency/priority of the needed information.

10. Vessel Information: Vessel information was an output of the proposed system. A Node 5 user inputs required data on his own vessel and send this information to Node 4.

11. CMA Information: CMA Information was defined as an Input to the proposed system. CMA Information provided by Node 4 to the system consists of information fused and analyzed by the CMA architecture or Node 4.

12. Scalable Bandwidth: Scalable Bandwidth was defined as an output of the proposed system and depends on the user requirements and priorities for receiving updated information.

13. Validated Authentication: Validated authentication was defined as an output of the proposed system. The Node 5 user requests authentication as an input. The output of this request is the validated authentication. Without a valid authentication Node 5 is unable to connect to the CMA architecture.

14. Own Ship Position: Own ship position was defined as an output of the proposed system and gives the geolocation information for the vessel.

The value of the input-output analysis is in the big picture view of the system inputs and outputs and boundaries. It provides a succinct, singular view of the system interdependencies and provides insight into the development of the Functional Analysis.

1. Functional Analysis

A functional analysis was performed to understand the proposed system from a functional viewpoint. The functional description allows for the system to be designed independent of any specific technical solution. This facilitates the evaluation of all technical options prior to implementing a specific technical approach. A functional decomposition provides reasons for the different physical components or equipment selected to implement the system. Thinking of the system in functional terms provides a basis for developing innovative alternatives.

For the xCMA system, the high level functionality consists of three functions, *Connect with CMA*, *Provide Collaboration,* and *Manage Information*. The definitions of these functions are shown below.

- 1.0 Connect with CMA – functionality involved with physically connecting the disconnected vessel with the Node 4 Functional Gateway, including locating and identifying the system.

- 2.0 Provide Collaboration – bidirectional communication between the disconnected node, Node 5, and the Node 4 gateway. This includes sending, receiving and displaying all information including web services, UDAP, COI Database, etc.

- 3.0 Manage Information – managing and handling of information local to the disconnected node. This includes data storage, and send, search and retrieval functionality.

These functions are then further analyzed to detail the lower level subfunctions as part of the functional decomposition. This functional decomposition is detailed in Figure 9 and a description of each function is listed in Table 4.

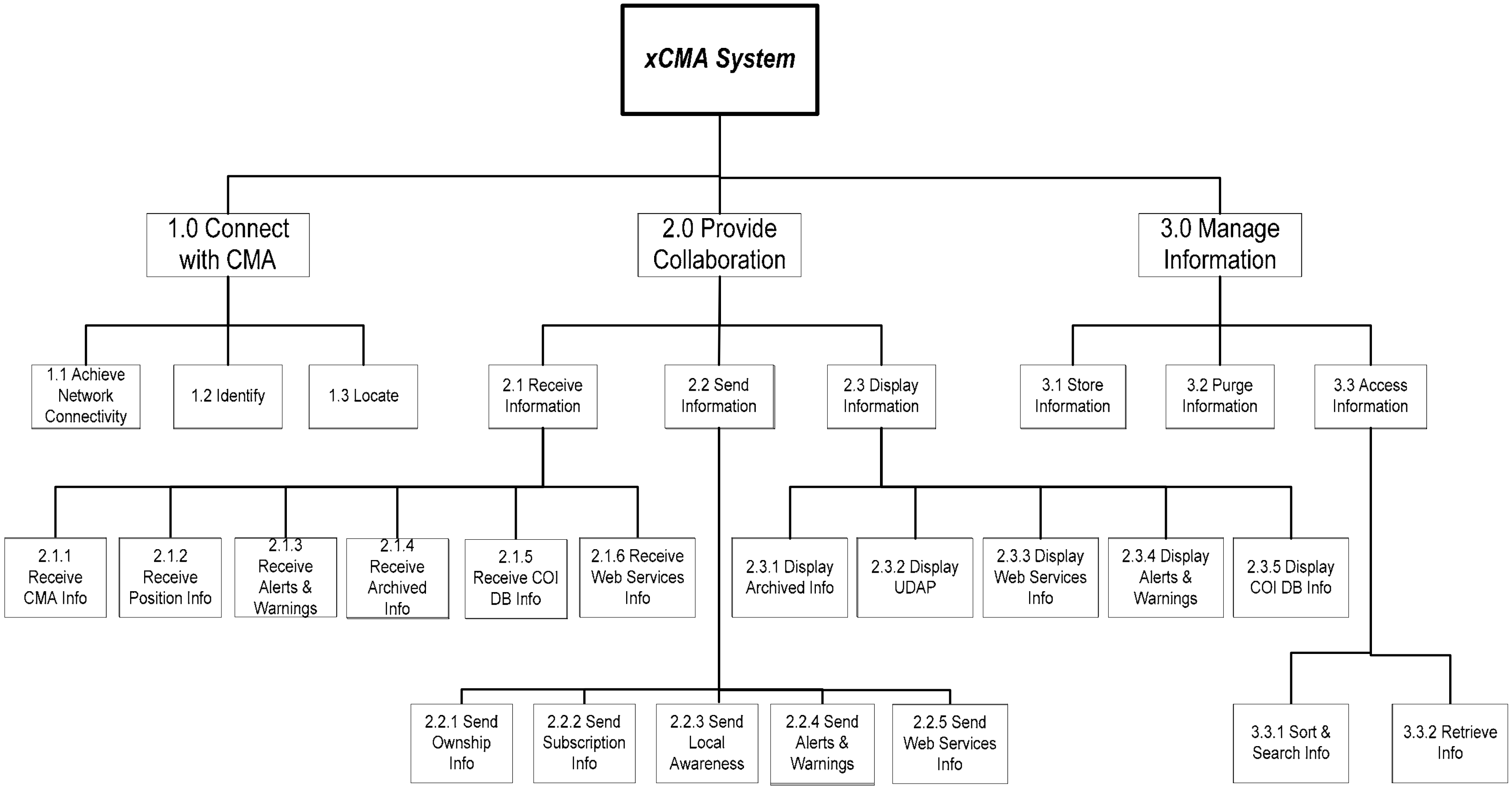

Figure 9. xCMA Functional Decomposition.
This figure details the decomposed functions and sub-functions of the xCMA system as derived from the system requirements defined in the Problem Definition Phase.

Assumptions:

1. Node 5 stores 48 hours of data locally

Table 4. xCMA Function and Sub-function Descriptions

Reference	Function	Definition
1.0	**Connect with CMA**	This category of functions includes the functionality involved with physically connecting the disconnected vessel with the Node 4 Functional Gateway, including locating and identifying the system and vessel.
1.1	Archieve Network Connectivity	This function represents the direct network connection, (RF, Satellite etc)from Node 4 and the xCMA system including the hardware connectivity, the handshaking and network negotiations.
1.2	Identify	This function represents the unique hardware identification of the xCMA system itself. For example, this may include the unique Media Access Control (MAC) address or on-chip hardware identification.
1.3	Locate	This function represents the ability of the xCMA system to obtain it's location via a global positioning system or equivalent.
2.0	**Provide Collaboration**	This category of functions includes bi-directional communication between the disconnected node, Node 5, and the Node 4 gateway. This includes sending, receiving and displaying all information including web services, UDAP , COI DB etc.
2.1	Receive Information	This function represents the ability of the system to receive all incoming CMA information or system operational inputs. Each of the following functions identify the category of information or data being received. This information includes::
2.1.1	Receive CMA Info	CMA Information
2.1.2	Receive Position Info	Position Information
2.1.3	Receive Alerts & Warnings	Alerts & Warnings Information
2.1.4	Receive Archived Info	Archived Information
2.1.5	Receive COI DB Info	COI DB Information
2.1.6	Receive Web Services Info	Web Services Information
2.2	Send Information	This function represents the ability of the system to send relevent and required information or data. This information includes::
2.2.1	Send Ownship Info	Vessel Information and Ownship Position
2.2.2	Send Subscription Info	Subscription Information
2.2.3	Send Local Awareness	Local Awareness - on-board sensor information
2.2.4	Send Alerts & Warnings	Local Alerts & Warnings Information
2.2.5	Send Web Services Info	Node 5 Web Services Information
2.3	Display Info	This function represents the ability of the system to display all CMA relevent information. This information includes::
2.3.1	Display Archived Info	Previously stored information
2.3.2	Display UDAP	Vessel requested awareness picture
2.3.3	Display Web Services Info	Node 5 Web Services Information
2.3.4	Display Alerts & Warnings	CMA Alerts & Warnings Information for AOI
2.3.5	Display COI DB Info	Requested COI DB Information
3.0	**Manage Information**	This function represents the ability of the system to retain and provide access to 24-48 hours worth of information.
3.1	Store Information	This function represents the ability of the system to store the received information.
3.2	Purge Information	This function represents the ability of the system to delete previously stored information, either based on a time dependent action or user request.
3.3	Access Information	This function represents the ability of the system to access previously stored information.
3.3.1	Sort & Search Info	This function represents the sort and search capability of the system that supports the ability to display archived information as requested by the user.
3.3.2	Retrieve Info	This function represents the ability of the system to retrieve the previously stored information.

The hierarchy of functions is generated from the functional decomposition. It starts with the effective need statement and supports decomposition of existing functions into subfunctions to provide a more accurate view of current functionality. This facilitates the identification of the objectives and evaluation measures for all lower level functions. These objectives and their corresponding evaluation measures are shown in Table 5. The sources of the values used in the evaluation measures were a combination of guidance from standards documents (i.e. Mean Time Between Failure (MTBF) = 1500 hours (hrs), MIL-PRF-28800F), similar functional systems, and expert knowledge. All system availability numbers assume that the network and all components of the system are fully functional. Therefore, the system availability of 100% for *Receipt of Alerts & Warnings* represents the expectation that all of these high priority alerts will be received when the xCMA system, Node 4 and the connecting network are fully functional. Data correctness refers to the format of the information received, sent and/or displayed. The Functional Hierarchy for the xCMA system is depicted in Figure 10.

Finally functional flow block diagrams were developed to show the functional interactions and provide a better understanding of the system. These tools were utilized to collectively come to better understanding of the process required to extend CMA to a disconnected vessel. The flow diagram also identified those functional elements conducted in parallel, and those requiring feedback loops. During the analysis, the flow was reviewed to ensure that the process accurately represented the system that was being modeled. The functional flow block diagram is included in Appendix C and was useful in detailing system interaction and determining the functional relationships, redundancies and dependencies.

Table 5. xCMA Function and Sub-function Objectives and Evaluation Measures

Reference	Function	Objectives	Evaluation Measures
1.0	**Connect with CMA**		
1.1	Archieve Network Connectivity	Establish and maintain connectivity	Network Up Time = 95% MTBF = 1500 Hrs
1.2	Identify	Maximize Accuracy	Identification Accuracy=100%
1.3	Locate	Maximize Accuracy	Location Accuracy within +/- 10 m
2.0	**Provide Collaboration**		
2.1	Receive Information		
2.1.1	Receive CMA Info	Increase Data Availability & Accuracy	Data Accuracy = 90%; A0=90%
2.1.2	Receive Position Info	Maximize Accuracy & Availability	Accurate within +/- 10 m; Available 95%
2.1.3	Receive Alerts & Warnings	Increase Data Availability & Priority	A0=100%
2.1.4	Receive Archived Info	Maximize Data Availability	A0=90%
2.1.5	Receive COI DB Info	Maximize Data Availability	A0=90%
2.1.6	Receive Web Services Info	Increase Data Availability & Accuracy	Data Accuracy = 90%; A0=90%
2.2	Send Information		
2.2.1	Send Ownship Info	Increase Data Correctness	Probability that the Data is Correct 95% of the time
2.2.2	Send Subscription Info	Increase Data Correctness	Probability that the Data is Correct 95% of the time
2.2.3	Send Local Awareness	Increase Data Correctness	Probability that the Data is Correct 95% of the time
2.2.4	Send Alerts & Warnings	Increase Data Correctness	Probability that the Data is Correct 95% of the time
2.2.5	Send Web Services Info	Increase Data Correctness	Probability that the Data is Correct 95% of the time
2.3	Display Info		
2.3.1	Display Archived Info	Increase Data Correctness	Probability that the Data is Correct 95% of the time
2.3.2	Display UDAP	Increase Data Correctness	Probability that the Data is Correct 95% of the time
2.3.3	Display Web Services Info	Increase Data Correctness	Probability that the Data is Correct 95% of the time
2.3.4	Display Alerts & Warnings	Increase Data Correctness	Probability that the Data is Correct 95% of the time
2.3.5	Display COI DB Info	Increase Data Correctness	Probability that the Data is Correct 95% of the time
3.0	**Manage Information**		
3.1	Store Information	Maximize Mission Capacity	Storage of nominal Mission Data=95%
3.2	Purge Information	Maximize Mission Capacity	Storage of nominal Mission Data=95%
3.3	Access Information		
3.3.1	Sort & Search Info	Minimize Data Access Time	Data Access < 10 s
3.3.2	Retrieve Info	Increase Data Availability & Accuracy	Data Access < 10 s

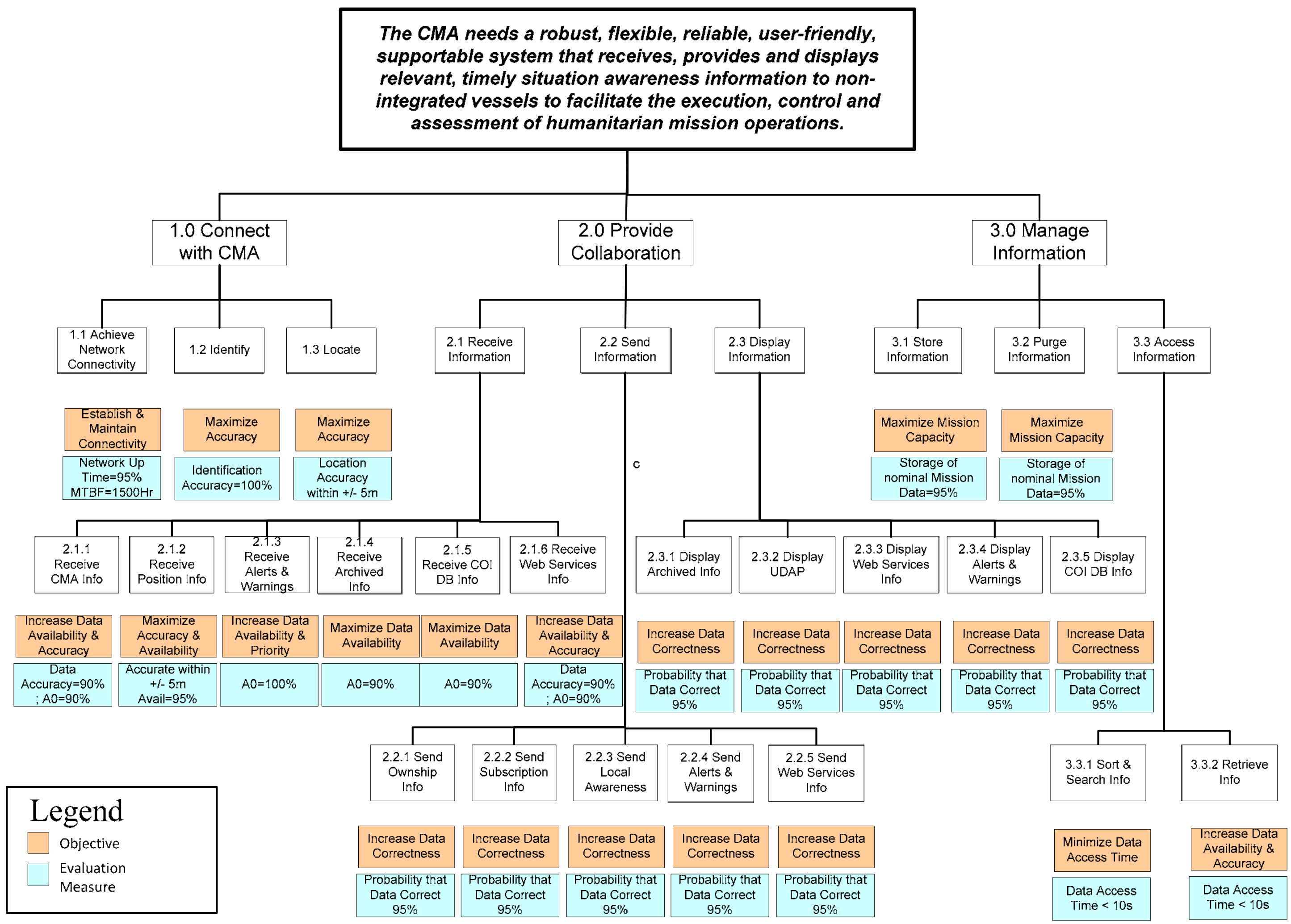

Figure 10. Top Level Hierarchy of Functions for the xCMA system.
This diagram shows the functions and sub-functions as defined in the functional decomposition and provided the identified objectives and evaluation measures.

In order to accurately capture the behavior and information flow through the xCMA system, Integration Definition for Function Modeling (IDEF0) was implemented. IDEF0 is a common modeling technique, a tool to aid in the functional analysis and was used to create a model for the proposed black box system. The IDEF0 model was used to show data flow, system control, and the functional flow of the proposed system to extend CMA to a disconnected Node 5. The model was created to provide a precise description of the proposed system and promote consistency in the terms being used and their interpretation. The IDEF0 products developed in support of this effort are located in Appendix D.

The IDEF0 model consists of a hierarchical series of diagrams and text. The two primary components are the functions and data that inter-relates to those functions. The IDEF0 model, in conjunction with the functional analysis, directly supported the generation of the Systems Communications Description System View (SV-2), which depicts pertinent information about communications systems, links and networks that support the xCMA systems. The SV-2 is one of several DoDAF products. The DoDAF is a tool that provides a common approach for describing, presenting, and integrating architectures. The product set describes a method of designing a system in terms of subcomponents, often referred to as building blocks, and detailing how they fit together. The SV-2 for the xCMA system is shown in Table 6.

Decomposing these functions further, resulted in the identification of subcomponents of interest which include interfaces and entities that make up the system. These functions are grouped based on subcomponent functionality. This functionality, along with the interfaces between the xCMA system and system nodes, is captured in the Systems Interface Description (SV-1) depicted in Figure 11. This diagram shows system nodes and the sub-systems resident at these nodes that support the information sharing between the Node 4 gateway and the disconnected Node 5 vessel. To augment the functional flow, and detail the information between the Node 4 and Node 5 systems, the Operational Information Exchange Matrix (OV-3) was generated. This matrix, shown in Table 7, defines the triggering events and the priorities of the information exchanges required of the xCMA system.

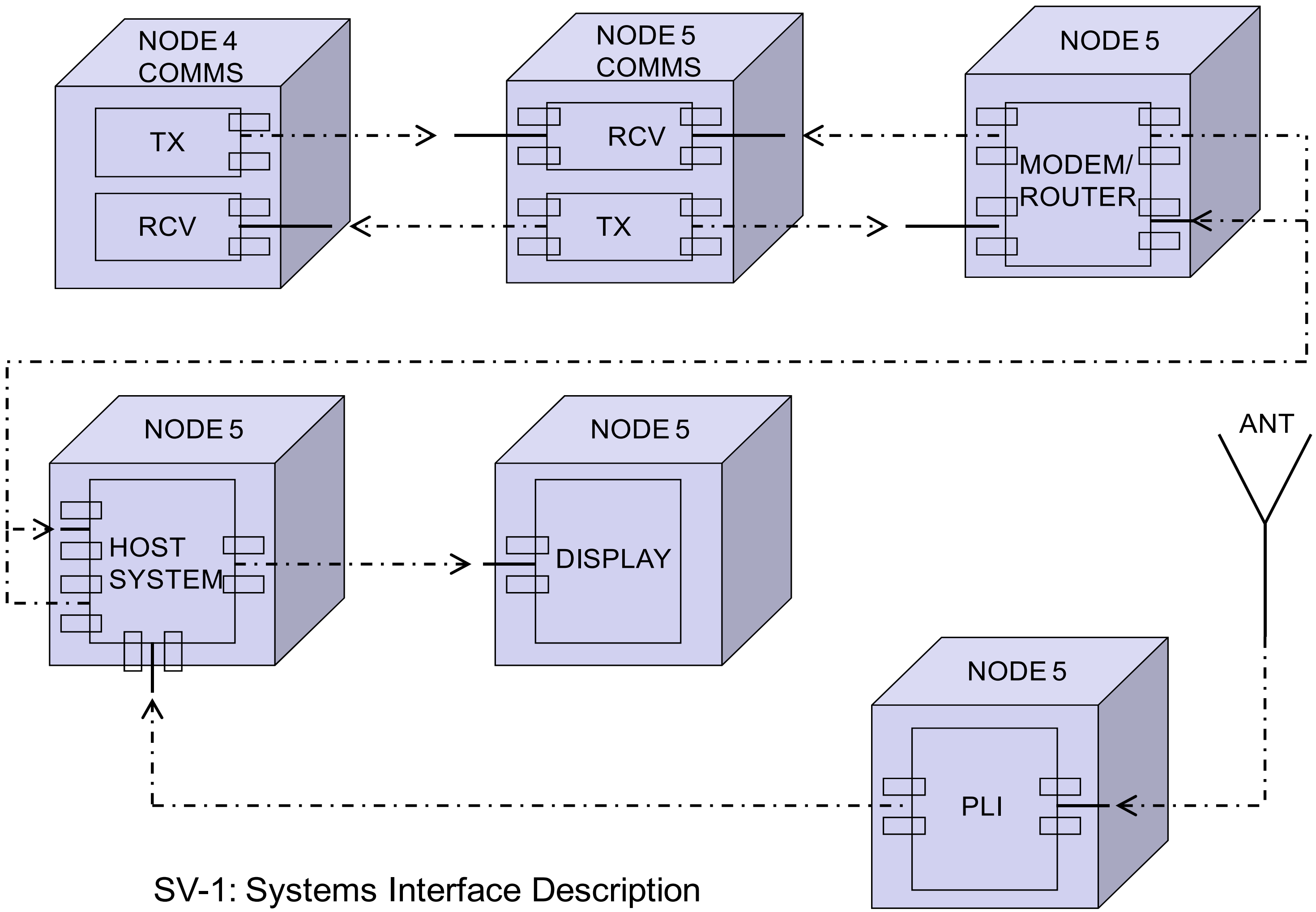

Figure 11. Systems Interface Description (SV-1).
This diagram details the system interactions, at the functional component level, for the xCMA system.

Table 6. Systems Communications Description (SV-2).

Need Line	Info Ex ID	Sending Op Node	Communication Links and Networks	Receiving Op Node
Subscription Information	1	Node 4	Radio Frequency (RF) Wireless Network/SOA	Node 5
Web Services Information	2	Node 4 Node 5	RF Wireless Network	Node 5 Node 4
COI Information	3	Node 4	RF Wireless Network/SOA	Node 5
Warnings & Alerts	4	Node 4 Node 5	RF Wireless Network/SOA	Node 5 Node 4
Local Awareness	5	Node 5	RF Wireless Network	Node 4
Authentication Request	6	Node 4 Node 5	RF Wireless Network	Node 5 Node 4
Geolocation Information	7	Node 5	RF Wireless Network	Node 4
UDAP	8	Node 4 Node 5	RF Wireless Network/SOA	Node 5 Node 4
Bandwidth Allocation	9	Node 4	RF Wireless Network	Node 5
Vessel Information	10	Node 5	RF Wireless Network/SOA	Node 4
CMA Information	11	Node 4	RF Wireless Network/SOA	Node 5
Scalable Bandwidth	12	Node 4	RF Wireless Network	Node 5
Validated Authentication	13	Node 4	RF Wireless Network	Node 5
Own Ship Position	14	Node 5	RF Wireless Network/SOA	Node 4

The SV-2 Systems Communications Description table details need lines for the communication, the sending and receiving nodes, communication links and network links.

Table 7. Operational Information Exchange Matrix (OV-3).

Need Line	Info Ex ID	Mission Scenario	Trigger Event	Timeliness	Sending Op Node	Receiving Op Node
Subscription Information	1	Provide Collaboration	Per Request	Routine	Node 4	Node 5
Web Services Information	2	Provide Collaboration	User	Routine	Node 4 Node 5	Node 5 Node 4
COI Information	3	Provide Collaboration	User	Routine	Node 4	Node 5
Warnings & Alerts	4	Provide Collaboration	Upon Receipt	Immediate	Node 4 Node 5	Node 5 Node 4
Local Awareness	5	Provide Collaboration	Upon Updates	Routine	Node 5	Node 4
Authentication Request	6	Connect with CMA	Upon Connection	Routine	Node 4 Node 5	Node 5 Node 4
Geolocation Information	7	Connect with CMA	Upon Connection and Periodic	Routine	Node 5	Node 4
UDAP	8	Provide Collaboration	Upon Updates	Routine	Node 4 Node 5	Node 5 Node 4
Bandwidth Allocation	9	Connect with CMA	Upon Connection	Routine	Node 4	Node 5
Vessel Information	10	Provide Collaboration	User	Routine	Node 5	Node 4
CMA Information	11	Provide Collaboration	Upon Connection and Updates	Routine	Node 4	Node 5
Scalable Bandwidth	12	Connect with CMA	Upon Connection	Routine	Node 4	Node 5
Validated Authentication	13	Provide Collaboration	Per Request	Immediate	Node 4	Node 5
Own Ship Position	14	Provide Collaboration	User	Routine	Node 5	Node 4

The OV-3 is a DODAF product that provides information regarding need lines, mission scenario, trigger events, timeliness, sending and receiving nodes.

The output of the Needs Analysis, which consists of all work done up to this point, is the revised problem statement, or Effective Need statement. It is created through iteration, feedback, and creativity during the processes utilizing System Decomposition, Stakeholder Analysis, and Functional Analysis. This Effective Need is stated below:

> *"The CMA needs a robust, flexible, reliable, user-friendly, supportable system that receives, provides and displays relevant, timely situation awareness information to non-integrated vessels to facilitate the execution, control, and assessment of humanitarian operations."*

In addition, amplification of terms referenced are as follows:

- *Robust - graceful degradation; ability to connect and communicate with the CMA via Node 4*
- *Flexible - plug and play capability, mission tailorable*
- *Reliable-operational availability of 0.90 with MTBF of 1500 hours*
- *User-friendly -automated and system-assisted help for user*
- *Supportable -Depot level maintenance only*
- *Relevant - user receives requested information*
- *Timely-in sufficient time to be of value to the user*

B. VALUE SYSTEM DESIGN

1. QFD

The QFD model was used to enhance the xCMA traceability of customer's high level needs to system functions and lower level attributes of potential system solutions. The QFD model facilitates the systems engineering decision making process through the scoring of the relationship strength between each requirement and attribute of the model and through the evaluation of the interaction for positive and negative impact among the model's attributes.

In this study, three QFD models were used to focus on the relationship between customer requirements and system level requirements, system level requirements and functional requirements, and functional requirements and evaluation measures. Figure 12 depicts these models graphically.

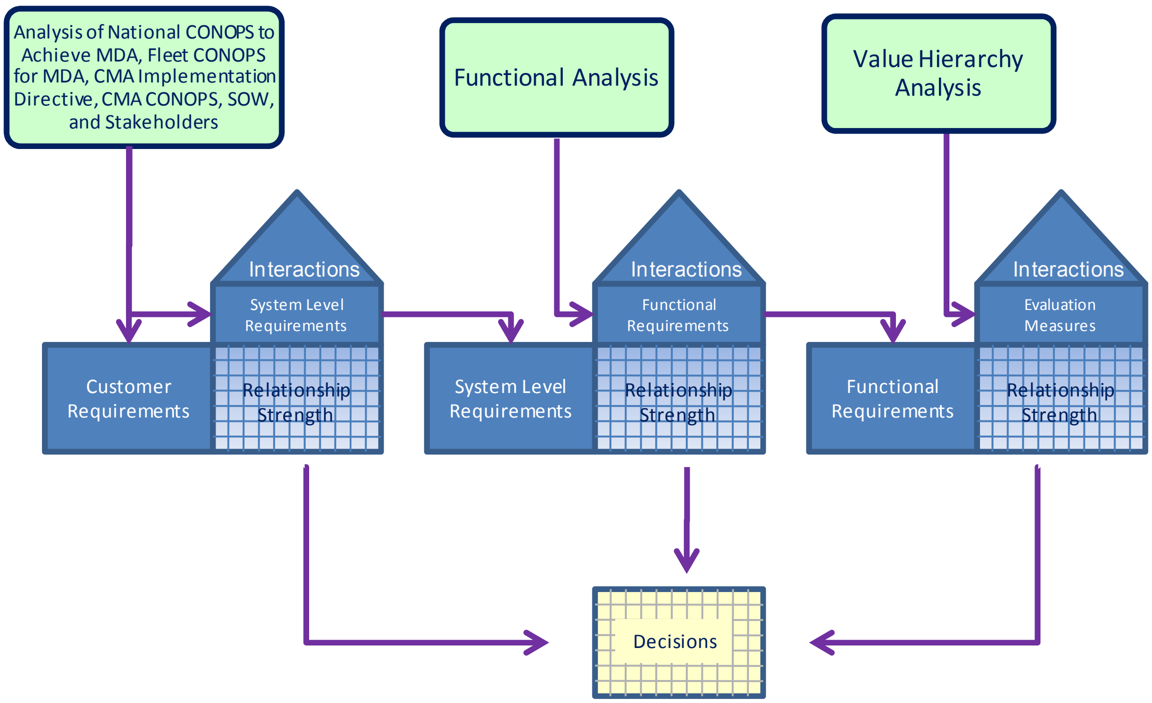

Figure 12. QFD models used in translating customer requirements into decision making attributes.
This figure also shows the sources of information and flow with dependency of the QFD models.

In this QFD analysis, the customer requirements and system level requirements are derived from the National CONOPS to Achieve MDA, Fleet CONOPS for MDA, CMA Implementation Directive, CMA CONOPS, SOW, and stakeholders. See Table 3 in Chapter 1 for specific reference of each customer requirement. The functional requirements are derived from the functional analysis. The evaluation measures are derived from the value hierarchy analysis.

In order to support the decision making process, the three QFD models were developed to methodically translate customer desires into quantifiable measures. The first translation starts with the customer requirements and system level requirements. This

analysis scores the relationship strength for the customer requirements with the system level requirements. Furthermore, the analysis evaluates the impact of interactions (positive, negative, neutral) within the system level requirements. The second translation uses the system level requirements to pair with the functional requirements. This analysis scores the relationship for the system level requirement and functional requirements. This analysis also evaluates the attribute interactions within the functional requirements. The third translation uses the functional requirements to bounce off the evaluation measures. This particular analysis scores the functional requirements with the evaluation measures. The analysis also evaluates the interaction within the evaluation measures. The QFD results are discussed in the sections below.

2. QFD with Customer Requirements and System Level Requirements

The interactions of the system requirements in the Pareto chart in Figure 13 indicate that an open architecture design, a plug and play interface, and graphical user interface have positive interaction with the core functions (connect, receive, transmit, display, and collaborate) in Node 5. Furthermore, maintaining a 0.90 operational availability and MTBF of 1500 hours have positive interaction with the core functions of Node 5 as well.

The Pareto results also illustrate the influence of the customer requirements. The top 20% of the attributes of the xCMA QFD for customer requirements and system level requirements indicate that the following are most important:

1. Displaying data and information from CMA Node 4
2. Receive data and information from CMA Node 4
3. Providing unclassified collaboration

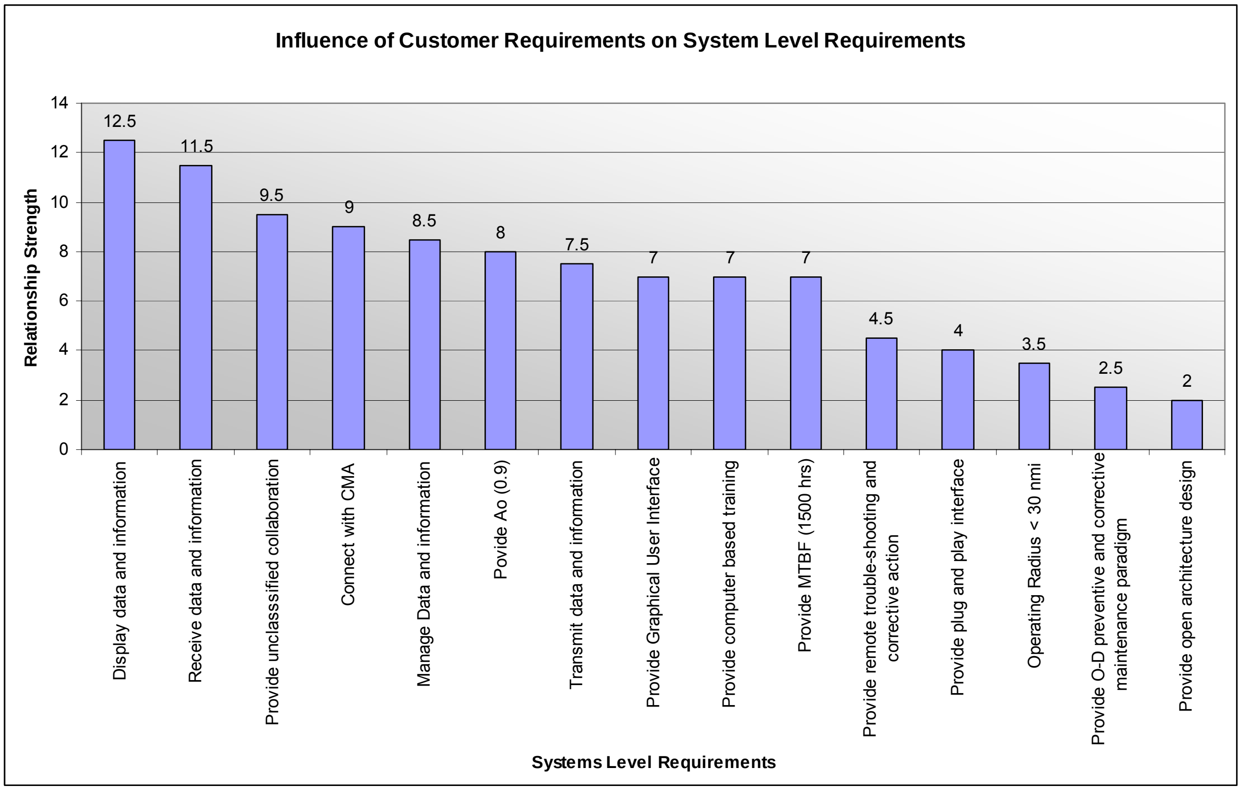

Figure 13. Influence of Customer Requirements on System Level Requirements for xCMA.
This Pareto chart helps identify the most important System Level attributes for decision making process.

3. QFD with System Level Requirements and Functional Requirements

The interactions of the system functions and sub-functions indicate both negative and positive interactions. The negative interactions are seen in the areas pertaining to system bandwidth and throughput. These include components supporting network operations, display and system storage. The Node 4 and Node 5 connection has positive impact on the core functions (connect, receive, transmit, display, and collaborate) in Node 5. This is the case because this connection is required by the xCMA node. The Pareto diagram in Figure 14 provides results to illustrate the influence of the system level requirements on functional requirements. The top 20% of the attributes of the xCMA QFD for system level requirements and system functions and sub-functions indicate that connecting with Node 4, sending subscription, displaying MDA UDAP, displaying web

services, displaying warnings and alerts, and displaying COI information have the highest influence strength.

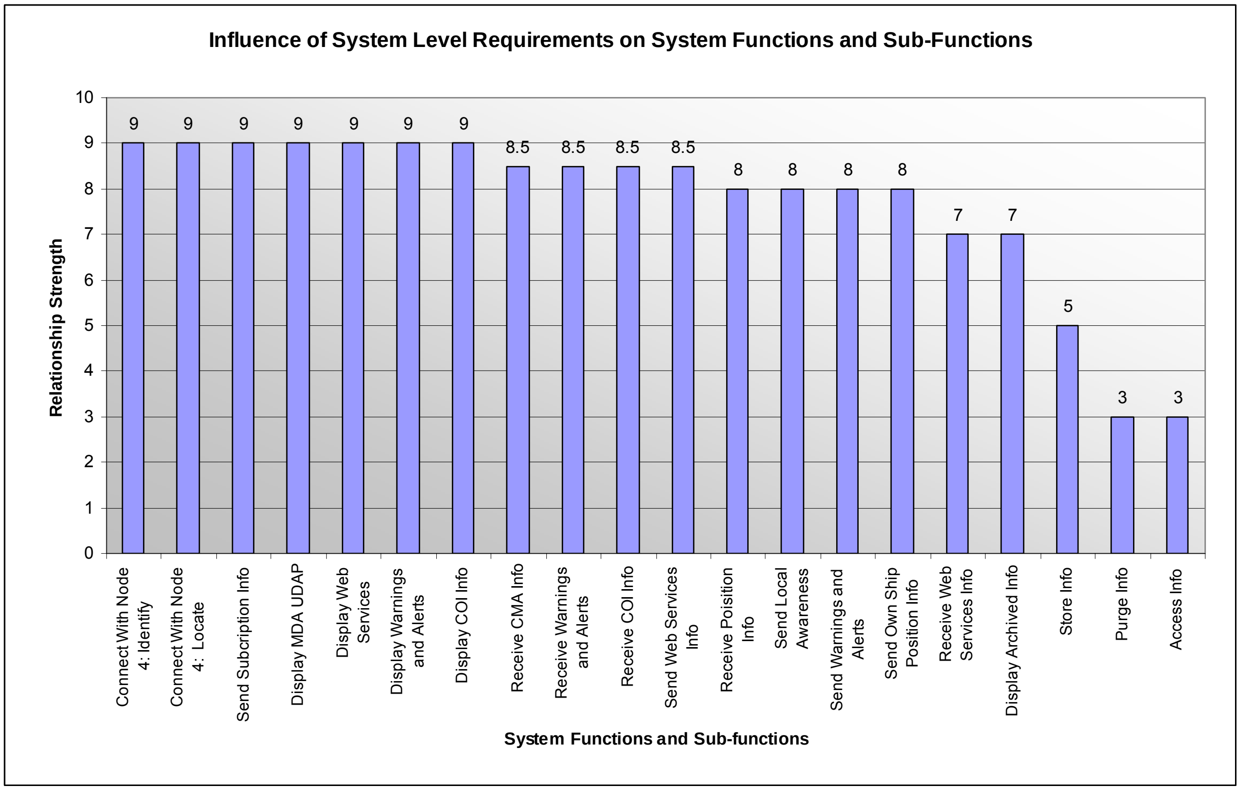

Figure 14. Influence of System Level Requirements on Functional Requirements for xCMA.
This Pareto chart helps identify the most important attributes for decision making process.

4. QFD with Functional Requirements and System Evaluation Measures

The interactions of the evaluation measures indicate negative interactions with regards to storage bandwidth limitations and data sort, search and retrieve time. Positive interactions are also identified in geolocation data accuracy, geolocation data availability, CMA data retrieved accuracy, CMA data availability, incoming warnings and alerts accuracy, and incoming warnings and alerts availability. This is the case because the CMA data and warnings and alerts are pulled from Node 4, which are based on the own ship location data.

Figure 15 below provides Pareto results to further illustrate the influence of the functional requirements on the evaluation measures. The top 20% of the attributes based on relationship strength from the xCMA QFD for functional requirements and evaluation measures indicate that network up time and network connectivity MTBF are the most important evaluation measures in extending CMA to Node 5.

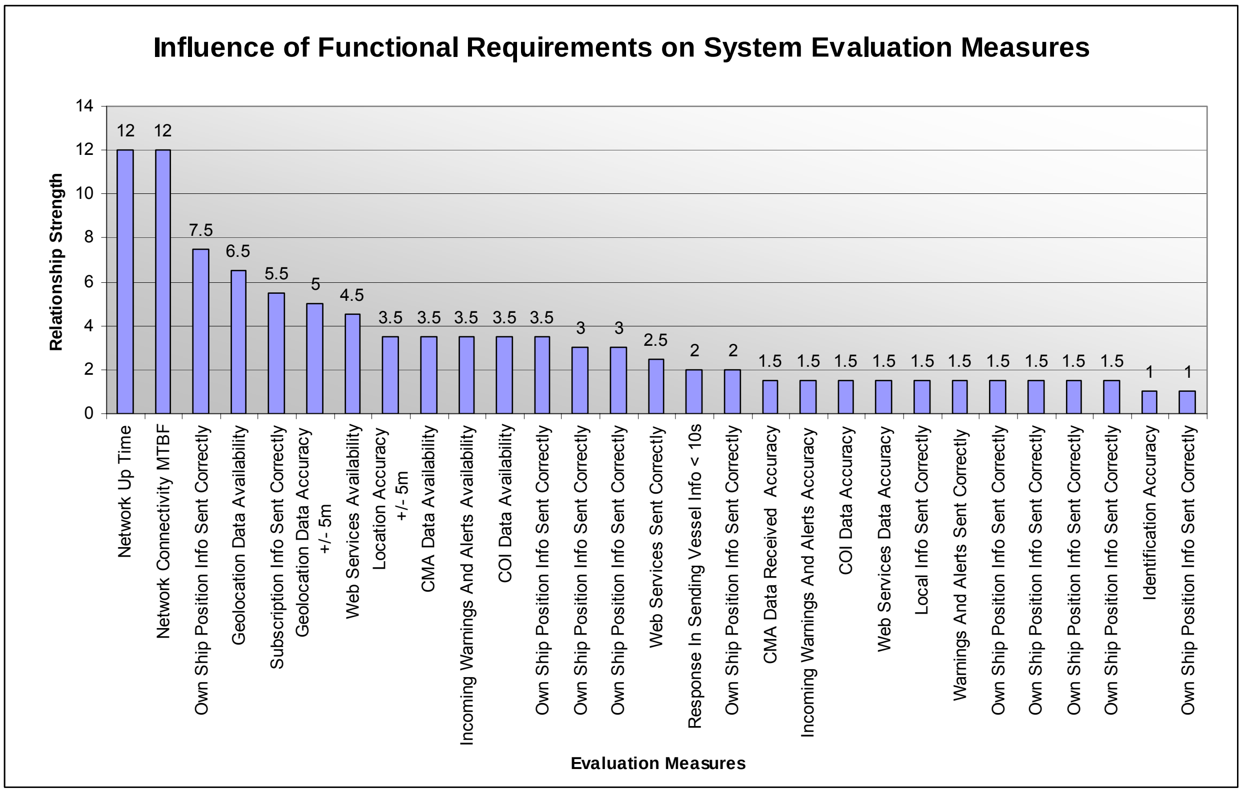

Figure 15. Influence of Functional Requirements on Evaluation Measures for xCMA.
This chart synopsizes the relationship between the functional requirements and stated evaluation measures. As shown, network up time and network connectivity (MTBF) are the two most influential measurements.

Following analysis of the Functional Hierarchy and QFD, the positive and negative evaluation measures were used to determine MOE for the xCMA system. These MOEs are:

MOE 1: Probability that, upon command, the system will be fully functional within 4 hours 95% of the time.

MOE 2: Probability that the system will connect to the CMA within 10 minutes 95% of the time. This includes network connectivity, system identification and geolocation.

MOE 3: Probability that the system will operate 1500 hours between failures 95% of the time.

MOE 4: Probability that the system will sustain data throughput of 0.128 Mbps 95% of the time.

In summary, the value system design phase evaluated the system requirements identified in the Problem Definition Phase, identified the functional requirements, objectives and evaluation measures and translated these requirements into engineering terms and MOEs. These activities directly support the next phase of the process, Design and Analysis, which will facilitate the generation of alternatives and support decision making.

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IV. DESIGN AND ANALYSIS

A. DESIGN & ANALYSIS

The next phase in the tailored systems engineering process is design and analysis. This phase consists of alternatives generation, including development of alternatives, feasibility screening, and modeling and simulation. Figure 16 illustrates the relationship of this phase to the overall process.

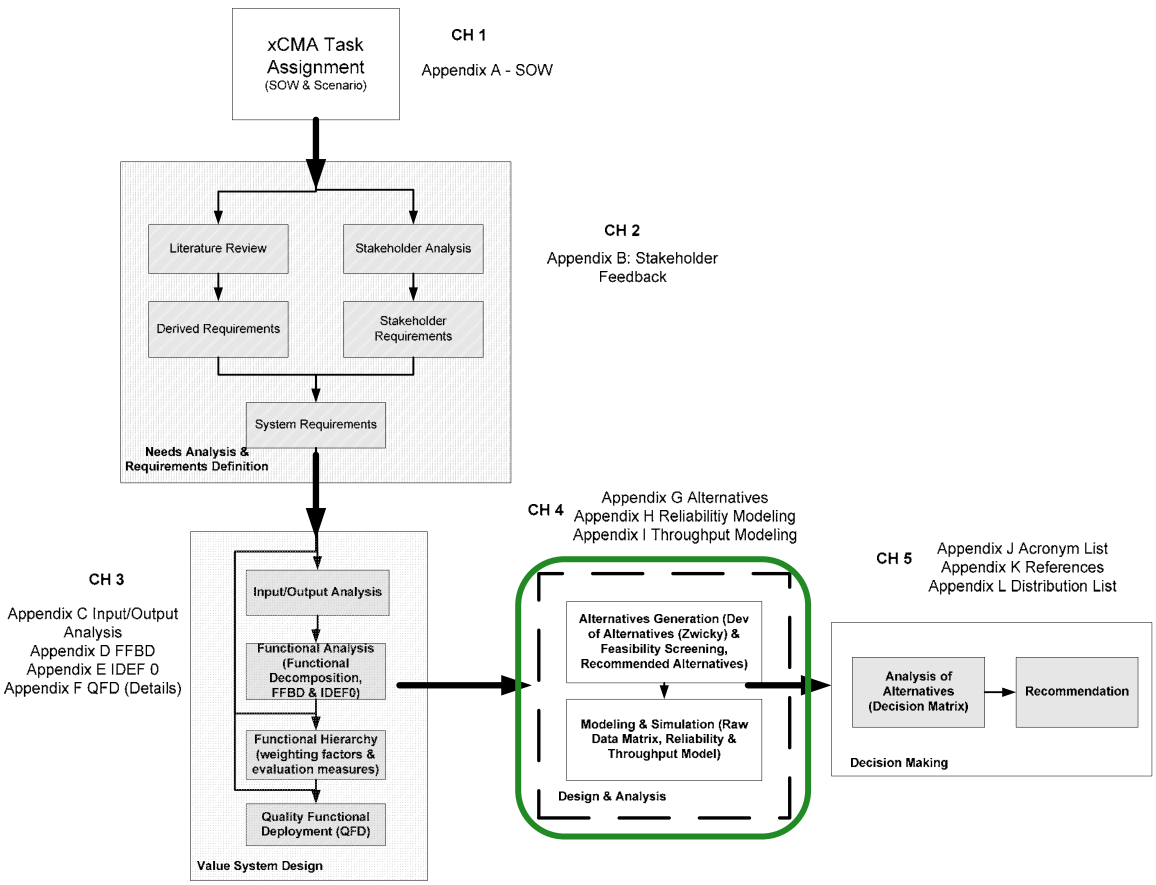

Figure 16. Design and Analysis Phase.
This phase details the relationship between this phase and the remainder of the system engineering process. The focus in this phase is on alternatives generation and modeling and simulation. These activity results will assist in the decision making process.

The purpose of these activities is to identify a set of key functions and evaluation measures to be used in the selection of the best candidate system configurations. These

candidate systems are then modeled and simulated. The results of the modeling and simulation provide guidance during the remainder of the system engineering process to ensure selection of the most appropriate system.

B. ALTERNATIVES GENERATION

The Alternatives Generation phase included the development of alternatives, feasibility screening and recommended alternatives. The results from the Functional Analysis, Functional Hierarchy, and QFD were utilized to focus the efforts in generating alternatives that meet the requirements. Alternatives generation identified the key system functions that the xCMA system requires to satisfy the effective need. These key functions were used in the development of the various xCMA system options. These options were then evaluated with the MOEs that were developed using the evaluation measures and QFD. This process is called feasibility screening. The screened system options were compiled into a list of recommended alternatives. These alternatives were then compiled into a Raw Data Matrix that highlights the key features of the xCMA system. The key features and representative functionality is modeled and simulated and the results used to assist in the evaluation and decision phase and in the selection of the most appropriate system.

1. Alternatives Generation Assumptions

- Due to the sensitive nature of military equipment, it would be restrictive to use military communications equipment
- 802.16m is a viable communication means by implementation date
- Web-based protocols are implemented
- INMARSAT, KU band, Ultra-High Frequency (UHF) SATCOM, Transformational Communications Satellite (TSAT) are combined into SATCOM
- Commercial SATCOM will use commercial router/modem and military SATCOM will use Tactical router/modem

- 802.16 implementation will use a commercial router/modem
- Host to Communications (COMMS) interface is condensed into commercial and tactical router/modem that will be internal to the xCMA system
- Software and services are developed and controlled by the CMA and will be loaded onto the host system prior to xCMA system delivery to the user
- Consideration of software and services is the responsibility of the CMA JCTD and will not be evaluated in this effort
- Display systems will be composed of conventional displays with an option for new technology
- User interface is part of the host system

2. **Alternatives Generation Critical information used early in the decision making process**

- Differential GPS (D-GPS) was excluded due to its limited operating area (requirement calls for a global solution)
- Software Defined Radios are flexible and can support a variety of networks (network agnostic) however they must be integrated with either SATCOM or Institute of Electrical & Electronics Engineers (IEEE) 802.16
- Wireless 802.11 IEEE range is less than 10 miles, therefore does not meet the 30 nm requirement
- INMARSAT bandwidth limitations are not feasible for handling streaming video

3. Development of Alternatives

The development of alternatives was the result of brainstorming and brainwriting activities to ensure all inputs were considered. To satisfy the effective need, the three previously defined functions from the Functional Hierarchy and Value Systems Design, (*Connect with CMA*, *Provide Collaboration* and *Manage Information*) were used during the ensuing evaluations. A reiteration of the definitions of these functions is shown below.

- 1.0 Connect with CMA – functionality involved with physically connecting the disconnected vessel with the Node 4 Functional Gateway, including locating and identifying the system.

- 2.0 Provide Collaboration – bidirectional communication between the disconnected node, Node 5, and the Node 4 gateway. This includes sending, receiving and displaying all information including web services, UDAP, COI, etc.

- 3.0 Manage Information – managing and handling of information local to the disconnected node. This includes data storage, and send, search and retrieval functionality.

A product matrix was generated identifying system categories required to meet the functionality and system objectives defined in the functional analysis above. The categories and identified options are displayed in Table 9 and were the result of several discussion and discovery sessions. From this product matrix, an initial set of 72 xCMA system options were generated. A table of these options, numerically identified, is included in Appendix F.

Table 8. Initial xCMA System Categories and Options

COMMS	Host System	HOST to COMMS Interface	PLI	Display	Identify	User Interfaces	Storage	Deployability
INMARSAT(L-Band)	PDA	Tactical Internal Router	DGPS - Internal	Color	NIC (Network Interface Card)	keyboard	Internal	Man
KU Band SATCOM		Tactical External Router				touch screen		
UHF SATCOM	Laptop	Commercial Internal Router		Multiple Displays		trackball		
HF-LOS		Commercial External Router	DGPS - External		IP Based	mouse	External	Ship
UHF-LOS	Desktop					voice recognitions		
VHF-LOS		Tactical Internal Modem	GPS - External	Size		mic / speakers		
Wireless (802.11/802.16)	PC Based	Tactical External Modem			Other Hardware	headset	Remote	
						camera		Helo
TSAT	Rack mounted SBCs	Commercial Internal Modem	GPS - Internal	Readable in bright light		bio recognition	Removable	
New Technology						card reader		
Software Definable Radios	Mobile Terminal Equipment	Commercial External Modem						
Evaluation Criteria								
Bandwidth Range >= 30 Nmi	Scalable Plug & Play Portable Expandable Supportable Maintainable Reliable	Properly interfaces between Host & COMMS	Accuracy = +/- 5meters	(HSI)	Accuracy = 100%	(HSI)	24-48 hours of information Probability =90-95% Access <10s Sort <10s Search < 10s	(HSI)

In an attempt to reduce the options to a viable set of alternatives, an additional functional evaluation of the overall system was applied. A conducted priority ranking was applied to each functional category based on the risk and impact that each has on the overall system and its objectives. A scale of 1 to 10 was applied with 10 representing the greatest impact. A decision was made by the engineering team to group together the display and host system categories. The rationale behind this decision was based on the understanding that the host system type is indicative of the associated display type. For example, a laptop solution for the host system determines a Liquid Crystal Display (LCD) for the display type. Figure 17 shows the final functional categories and the evolution from the original list with ranking/weighting values to the final top 5.

Functional Category	Ranking
Communications	10.0
Identify	9.5
Host to Comms Interface	9.0
PLI	9.0
Display	8.0
Host System	6.0
Deployability	5.0
User Interface	4.0
Storage	4.0

Functional Category
Communications
Identify
Host to Comms Interface
PLI
Host System (incl Display)
Deployability
User Interface
Storage

Figure 17. Functional Categories.
During alternatives generation, it was necessary to reduce the options to a realistic number. To accomplish these rankings were applied to the functional categories to determine which functional areas needed to be the focus. This diagram shows the evolution of these categories and their relative ranking factors.

It was determined that although *Manage Information* is an important part of the system, the functionality is easily satisfied by a variety of typical software and storage systems commercially available and is not a limiting factor of the xCMA system. For this reason, it was removed as a focal point for alternatives generation.

With *Manage Information* removed as a key focus, the primary functions for evaluation and consideration are reduced to *Connect with CMA* and *Provide Collaboration*. These functions represent the xCMA system's ability to physically connect to a CMA gateway, identify the vessel and the vessel's location, and to provide bidirectional communications and display capability for all data and services.

The product matrix previously generated was modified to represent the decisions identified above. Changes were also made regarding the COMMS category. First, due to the requirement to connect to a Node 4 gateway within a 30 nm range, the Line of Sight (LOS) options were removed. Second, the SATCOM category was identified as Commercial only due to the unclassified nature of communications and the need to connect with other nations and entities for humanitarian efforts. Research further showed that INMARSAT does not handle the streaming video requirements. In addition, new technology was determined not to meet a 2010 implementation schedule and therefore would not be evaluated due to the lack of system specifications available for evaluation. Upon defining MTE, it was determined that MTE was effectively another form of a SBC.

These two categories were combined under the SBC category. The resulting matrix is displayed in Table 9 and includes the following categories of focus; Communications, Host System, Router/Modem, Position Location Information, Display and Identify. The definition of each category is defined below.

Table 9. Revised xCMA System Categories and Options

<table>
<tr><th>COMMS</th><th>Host System</th><th>Router/Modem</th><th>PLI</th><th>Display</th><th>Identify</th></tr>
<tr><td>SATCOM-Commercial</td><td rowspan="2">Laptop</td><td rowspan="3">Commercial</td><td rowspan="5">GPS</td><td rowspan="3">LCD</td><td rowspan="3">NIC MAC Address</td></tr>
<tr><td>Wireless (802.16 or equiv)</td></tr>
<tr><td rowspan="2">SATCOM – Military / Government</td><td rowspan="2">New Technology</td></tr>
<tr><td rowspan="2">Tactical</td><td rowspan="2">New Technology</td><td rowspan="2">Other Hardware / New Technology</td></tr>
<tr><td>Software Definable Radios</td><td>SBC</td></tr>
<tr><td colspan="6">Evaluation Criteria</td></tr>
<tr><td>Bandwidth</td><td>Scalable</td><td>Properly interfaces between Host & COMMS</td><td>Accuracy = +/- 5meters</td><td>(HSI)</td><td>Accuracy = 100%</td></tr>
<tr><td>Range >= 30 nm</td><td>Plug & Play</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td>Portable</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td>Expandable</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td>Supportable</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td>Maintainable</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td>Reliable</td><td></td><td></td><td></td><td></td></tr>
</table>

- The COMMS components maintain connectivity to any CMA gateway within 30 nm from Node 5. It is a means that allows the xCMA system to communicate with a CMA gateway. The communications link can be in any format, such as

SATCOM or a wireless point to point link. The 30 nm requirement excludes consideration of Line-of-Sight (LOS) communications systems.

- The Host System is comprised of components that function as the computing and storage components for the xCMA system. The Host System also includes user interfaces that allow the xCMA user to input data, retrieve data, and communicate with the system. It is understood that current COTS personal computer systems are capable of handling throughput sufficiently greater than the required 0.128 Mbps of incoming data. For this reason, the detailed specific internal components of the Host System are not a constraint and therefore not evaluated.

- The Host to COMMS interface provides the functionality to relay transmitted information between the communications components and the Host system.

- PLI is used to accurately provide own ship position using GPS satellites. This information is reported to the CMA and is available to the ship personnel. This PLI can be generated automatically based on the GPS input or manually entered by the user as part of a query filter that is sent to Node 4 for UDAP data.

- The Display function component is used to display CMA data. This allows the presentation of information and data to the operator.

- The Identify function component is a requirement to provide a unique identifier for each xCMA system. This allows accurate logistics, provides some inherent security functionality, and is responsible for providing self-identification automatically and independently from the Node 5 user. In this study, the NIC is used to provide a unique 48-bit serial number called a MAC address. Another option is the IP.

- The Router/Modem provides the functionality to relay transmitted information and connect to the CMA network. It provides the network interface going from Node 4 and Node 5 xCMA system.

Table 10. Updated List of Alternatives

COMMS	Host System	Router/Modem	PLI	Display	Identify
SATCOM – Commercial	Laptop	Commercial	GPS	LCD	MAC/IP
M – Commercial	New Technology	Commercial	GPS	New Technology	Other HW, new tech
SATCOM – Commercial	SBC	Commercial	GPS	LCD	MAC/IP
SATCOM – Commercial	Mobile Terminal Equipment	Commercial	GPS	LCD	Other HW, New Tech
SATCOM - Military/Government	Laptop	Tactical	GPS	LCD	MAC/IP
SATCOM - Military/Government	New Technology	Tactical	GPS	New Technology	Other HW, new tech
SATCOM - Military/Government	SBC	Tactical	GPS	LCD	MAC/IP
SATCOM - Military/Government	Mobile Terminal Equipment	Tactical	GPS	LCD	Other HW, New Tech
Wireless 802.16	Laptop	Commercial	GPS	LCD	MAC/IP
Wireless 802.16	New Technology	Commercial	GPS	New Technology	Other HW, new tech
Wireless 802.16	SBC	Commercial	GPS	LCD	MAC/IP
Wireless 802.16	Mobile Terminal Equipment	Commercial	GPS	LCD	Other HW, New Tech
Software Defined Radio	Laptop	Commercial	GPS	LCD	MAC/IP
Software Defined Radio	New Technology	Commercial	GPS	New Technology	Other HW, new tech
Software Defined Radio	SBC	Commercial	GPS	LCD	MAC/IP
Software Defined Radio	Mobile Terminal Equipment	Commercial	GPS	LCD	Other HW, New Tech

Additional analysis was conducted to further refine the alternatives. The analysis included research on available technologies, earlier assumptions, and evaluation of requirements. Since the xCMA system is deployed to foreign allies and restrictions exist in the use of tactical equipment, all tactical equipment was eliminated from the list of alternatives. Software Defined Radios (SDRs) do not have their own communications means. To use SDRs either a wireless protocol or satellite communications system will need to be incorporated. Given this restriction SDRs are eliminated from the list of alternatives. The portability requirement eliminates the desktop and Cathode Ray Tubes (CRT) due to bulk and fragility. The final list of alternatives is shown in Table 11.

Table 11. xCMA System Alternatives

Alternatives	COMMS	Host System	Router /Modem	PLI	Display	Identify
1. SATCOM - Laptop	SATCOM - Commercial	Laptop	Commercial	GPS	LCD	MAC/IP
2. SATCOM-SBC	SATCOM - Commercial	Integrated SBC Mobile Terminal Equipment(MTE)	Commercial	GPS	LCD	MAC/IP
3. Wireless-Laptop	Wireless 802.16	Laptop	Commercial	GPS	LCD	MAC/IP
4. Wireless-SBC	Wireless 802.16	Integrated SBC (MTE)	Commercial	GPS	LCD	MAC/IP

A detailed account of alternatives generation is included in Appendix F and a design description of each of the alternatives follows.

Alternative 1: SATCOM-Laptop Alternative – A SATCOM capability is used as the communications means for connecting to the CMA network. The information from the host system laptop is routed through the modem and then transmitted by the satellite transmitter to the Node 4 satellite receiver. The information from Node 4 is transmitted by a satellite transmitter and received by the system satellite receiver and demodulated for processing by the host system laptop. The NIC provides the system with a unique hardware MAC address for the system identification. A COTS GPS receiver will be used to provide system PLI.

Alternative 2: SATCOM- SBC Alternative – A SATCOM capability is used as the communications means for connecting to the CMA network. The information from the host system MTE consisting of an SBC, modem/router, power supply, display, and input devices packaged in a ruggedized, transportable container is routed through the demodulator modem and then transmitted by the satellite transmitter to the Node 4 satellite receiver. The information from Node 4 is transmitted by a satellite transmitter and received by the system satellite receiver and demodulated for processing by the host system MTE. The NIC provides the system with a unique hardware MAC address for system identification. A COTS GPS receiver is used to provide system PLI.

Alternative 3: Wireless (802.16m)-Laptop Alternative – A wireless broadband communications capability is used as the communications means for connecting to the CMA network. The information from the host system laptop is transmitted by the RF transmitter to the Node 4 RF receiver. The information from Node 4 is then transmitted by the RF transmitter and received by the system RF receiver for processing by the host system laptop. The NIC provides the system with a unique hardware MAC address for system identification. A COTS GPS receiver is used to provide system PLI.

Alternative 4: Wireless (802.16m)-SBC Alternative – A wireless broadband communications capability is used as the communications means for connecting to the CMA network. The information from the host system MTE consisting of an SBC, modem/router, power supply, display, and input devices packaged in a ruggedized, transportable container will is transmitted by the RF transmitter to the Node 4 RF receiver. The information from Node 4 is transmitted by the RF transmitter and received by the system RF receiver and demodulated for processing by the host system MTE. The NIC provides the system with a unique hardware MAC address for system identification. A COTS GPS receiver is used to provide system PLI.

C. FEASIBILITY SCREENING

Feasibility Screening facilitates solution selections for the four system alternatives. The purpose of this activity is to validate, at a high level, the realistic applicability of the defined alternative as a solution for the defined problem. This is accomplished by evaluating the alternatives using the previously developed MOEs and Evaluation Criteria. Table 12 details the results of the feasibility screening of the four identified system alternatives and a non-materiel solution.

Table 12. xCMA System Feasibility Screening

Design Name	Feasibility Criteria				
	>30 nm Range	Communications Network Interface	Display Data & Info Correctly	Identification Accuracy 100%	SUMMARY
SATCOM-Laptop	G	G	G	G	G
SATCOM-SBC	G	G	G	G	G
Wireless-Laptop	G	G	G	G	G
Wireless-SBC	G	G	G	G	G
Non-Materiel	NG	NG	NG	NG	NG

G	-	Go
NG	-	No Go
Green	-	Meets requirements
Yellow	-	Does not fully meet requirements
Red	-	Does not meet requirements

A Non-Materiel solution is included during feasibility screening to ensure that all possible solutions are considered. The non-materiel solution uses existing networks and infrastructure and focuses on modification of mission responsibilities, operational concepts and technologies. Existing systems do not meet the system requirements to provide adequate CMA connectivity to the disconnected vessel or user. Limited connectivity could be provided on an adhoc basis using existing Ultra High Frequency (UHF)/Very High Frequency (VHF) radio telephones and possibly messenger services (small boat and helicopter delivery of maps, orders). This does not provide a sustained capability for Node 5 to effectively and efficiently communicate with the humanitarian operation vessels using streaming video, text, pictures, e-mail, and chat. This solution does not provide the required Node 5 connectivity.

The SATCOM alternatives, both laptop and SBC, satisfy all of the identified feasibility criteria. The Wireless (802.16m) alternatives, both for laptop and SBC, satisfy the feasibility criteria with an associated risk due to immaturity of the standard. This risk

is associated with the range limitations of the current 802.16e standard. 802.16m has better mobility and increased range as well as higher throughput rates. However, this version (IEEE Specification C802.16m – 07/003) is still in work and not yet formally released. Therefore, the feasibility criteria related to range and 100% identification are identified as risk areas.

D. MODELING & ANALYSIS

In system engineering, a model is developed to evaluate the measures of effectiveness of a system being designed. The created model is an incomplete representation of reality, an abstraction of the system. Furthermore, the created models in this study are mathematical abstracts of the system. A random number generator is used to model the propensity of the system characteristics. The modeling and analysis phase includes the raw data matrix, reliability modeling, and the throughput modeling.

1. Raw Data Matrix

The Raw Data Matrix highlights several features of the xCMA system. The specific information is supported by the modeling contained in the following sections. The throughput (≥ Mbps) measurement is a simple function of the peak bandwidth capabilities based on COTS hardware components. The data is generated using hardware performance values from multiple SATCOM terminal systems, 802.16 wireless systems, personal laptop computers, SBCs, router/modems, LCD monitors, and NICs.

Some critical assumptions about the system include the following. First, the processor speed and throughput are not an issue of concern for this system as a generic COTS personal computer would adequately handle processing requirements. Second, Network Time Allocations are not under the control of the xCMA system and are not used in the throughput calculations.

Table 13. Raw Data Matrix for the xCMA system

Evaluation Measure	Alternatives			
	SATCOM-Laptop	SATCOM-SBC	Wireless-Laptop	Wireless-SBC
System Functional $\leq$ 4 hours	**Y**	**Y**	**Y**	**Y**
Connect to CMA $\leq$ 10 minutes	**Y**	**Y**	**Y**	**Y**
The system will be up and operational at least 1500 hours between failures. MTBF (hours) $\geq$ 1500	**91.52%**	**94.43%**	**94.76%**	**97.77%**
The probability that the system will be able to meet the required data throughput 95 % of the time Throughput $\geq$ 0.128 Mbps	**99.57%**	**99.57%**	**99.97%**	**99.97%**

Note to Table 13: Estimated data points are in **PURPLE**; Hard Data points are in **Black.**

2. Reliability Modeling

A mathematical model was used to evaluate system reliability. For reliability to be measured, the system must be under a specific set of maintenance and operational conditions. Reliability is treated as a probability and therefore has a distribution.

From the Raw Data Matrix, the MTBF was selected to measure the reliability of the system. The values of the MTBF for the different system components were obtained by averaging the published MTBF values obtained from similar products.

The reliability model of the system consists of five component categories as detailed in Table 14. The reliability for each component as a function of mission time (R(t)) can be then calculated by using the following equation:

$$R(t) = e^{\frac{-t}{MTBF}} \qquad \text{Eq. (1)}$$

The total reliability of each alternative was calculated using the series system formula as follows:

$$R_{System} = R_1 \times R_2 \times R_3 \times R_4 \times R_5 \qquad \text{Eq. (2)}$$

The mission time of 14 days (336 hours) is used in the calculations and the value for each component's reliability is shown in Table 14.

Table 14. xCMA System Component Reliability Calculations

Components	System Reliability
Communications: SATCOM-Commercial	96.36%
Communications: Wireless 802.16	99.76%
Host System: Laptop	96.69%
Host System: Single Board Computer (MTE)	99.77%
Router/Modem: Commercial	99.95%
Display: LCD	98.52%
Identify: MAC Address	99.76%

To determine the simulated system alternative reliabilities, the components of each alternative were grouped together. Each alternative was simulated using Microsoft Excel with a random function. Each model was simulated with 300 replications to reach result stability and ensure a 95% confidence interval. The results are summarized in Table 15. The detailed simulated results are shown in Appendix G.

Table 15. Simulated xCMA System Reliability Results for the Alternatives

Alternatives	Reliability Simulations Results
SATCOM-Laptop	91.52%
SATCOM-SBC	94.43%
Wireless-Laptop	94.76%
Wireless-SBC	97.77%

The simulated system reliability values in Table 15 above were then used to calculate the system MTBF values. The system MTBF results are shown in Table 16 and are used in conjunction with the MTBF Multi-Attribute Utility Theory (MAUT) to determine a weighted score for each of the alternatives.

Table 16. Simulated xCMA System MTBF Results for the Alternatives

Alternatives	Simulated MTBF Results (hrs)
SATCOM-Laptop	3,794
SATCOM-SBC	5,863
Wireless-Laptop	6,246
Wireless-SBC	14,880

3. Throughput Modeling

Throughput is one evaluation measure in the Raw Data Matrix. For the xCMA system modeling and simulation, throughput is referred to transmission performance of data and is measured by transmitted or received data during a certain period of time. The throughput of a connection depends on the Central Processor Unit (CPU), memory, and any other processing components that are linked together. Throughput is a measure in megabits per second (Mbps). The requirement for the xCMA system has been defined by the stakeholders as greater than or equal to 0.128 Mbps.

To measure and analyze the throughput of the system, a model similar to that of reliability was used. The system components are connected in series.

The throughput model data is based on research of similar systems in the commercial sector. Each alternative's components are assigned with average values of throughput from manufacturer's published values. Since the model was created with components connected in series, the overall system throughput could be determined by the subcomponent that has the lowest throughput for each alternative. This can be represented as follows:

$$T_{System} = Min(T_1, T_2, T_3, T_4, T_5) \quad \text{Eq. (3)}$$

Based on the system throughput equation above, each of the components has a calculated throughput value as shown in Table 17. The detailed throughput calculations and results are shown Appendix G.

Table 17. xCMA System Component Throughput Calculations

Component	Throughput (Mbps)
Communications: SATCOM-Commercial	0.235
Communications: Wireless 802.16	100
Host System: Laptop	322
Host System: SBC (MTE)	2,008
Router/Modem: Commercial	3.729
Display: LCD	1,064.960
Identify: MAC Address	235.000

The model uses a random exponential arrival and service distribution. The evaluation measures from the Raw Data Matrix of the xCMA system alternatives are simulated and captured for comparison. Each component's throughput is simulated with 30 replications (500 runs each). The throughput results are shown in Table 18 and detailed results are shown in Appendix G. The results indicate that all alternatives meet the minimum required throughput of 0.128 Mbps. Also, the simulated results support the evaluation measures in the Raw Data Matrix.

Table 18. Throughput Simulations Results for xCMA System Alternatives.

Alternative	Required Throughput Met?	The probability that 95 % of the time Throughput ≥ 0.128 Mbps
SATCOM-Laptop	Yes	99.57%
SATCOM-SBC	Yes	99.57%
Wireless-Laptop	Yes	99.97%
Wireless-SBC	Yes	99.97%

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V. DECISION MAKING AND RECOMMENDATIONS

A. DECISION MAKING

The final phase in the tailored systems engineering process is decision making. This phase consists of Analysis of Alternatives and Recommendation as shown in Figure 19.

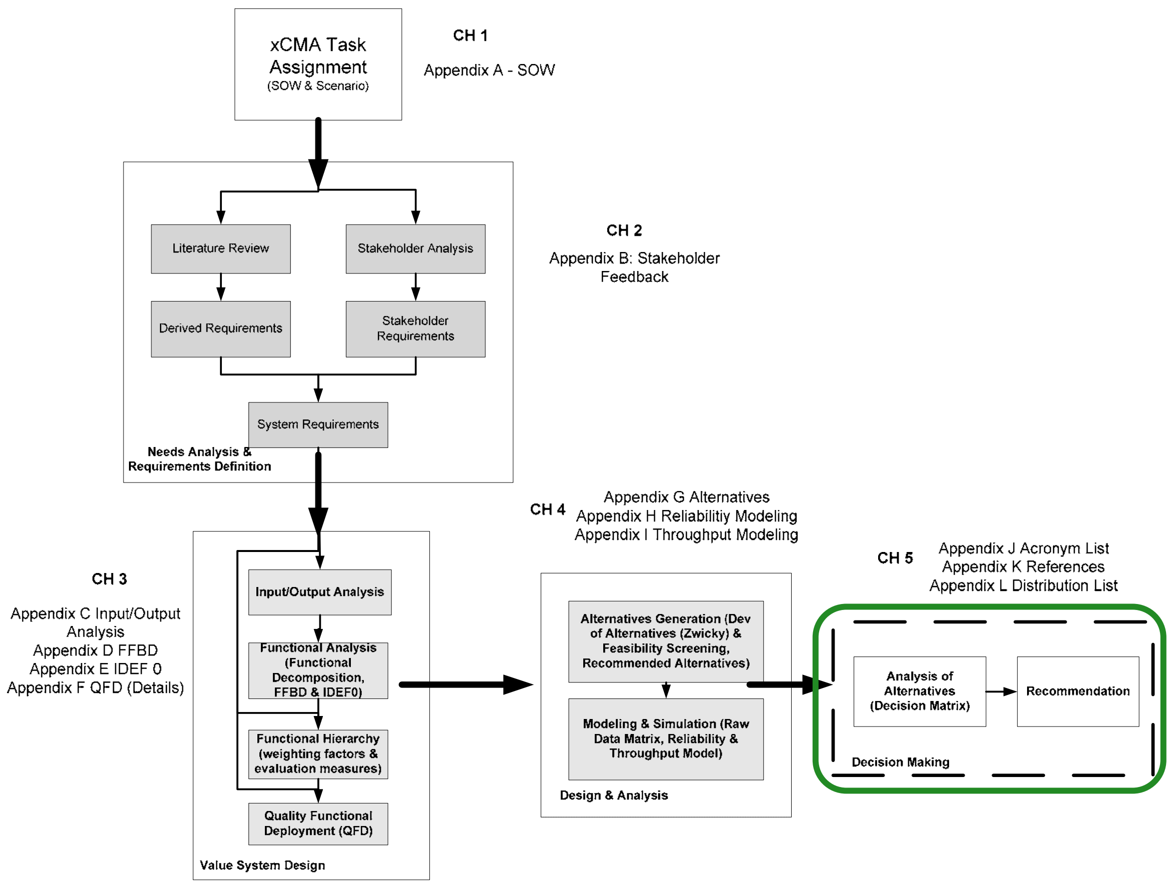

Figure 19 Decision Making Phase. This figure highlights the Decision Making activities completed in the tailored system engineering process.

The purpose of these activities is to analyze the viable alternatives from the Design and Analysis phase and to numerically score the alternatives so that a final recommendation can be given to the stakeholders. The analysis of alternatives includes

the development of MAUT scores, a decision matrix, and sensitivity analysis. The results from these work products were then used in the final recommendation.

1. Decision Matrix

The Decision Matrix is the result of the application of global weights and MAUT scores on the four xCMA system alternatives. MAUT provides a systematic, objective, and quantitative way of identifying and analyzing multiple variables and objectives to form a common basis for arriving at a decision. The MAUT utilities are captured from the stakeholders with the level of importance of each utility reflecting the preference of the stakeholders.

MTBF was one of the evaluation measures examined and applied with MAUT. Research of similar current systems provided MTBF data for each system component. This data was statistically analyzed and the mean value was used in the simulation. Table 19 provides the values from the simulation. This data was used to extract the corresponding value from the MAUT curve as displayed in Figure 20.

Table 19. xCMA System Alternatives Mean Time Between Failure Comparison

Ranking	Alternative	MTBF (Hrs)	Symbol
1	Wireless - SBC	14,880	⬟
2	Wireless - Laptop	6,246	◆
3	SATCOM-SBC	5,863	✚
4	SATCOM-Laptop	3,794	▲

Table 19 summarizes the outcome of the modeling and simulation results for each alternative. These results were based on existing systems reliability data. The results are ranked according to their resulting mean time between failure data. A MTBF of equal or greater than 1500 hours was determined to be the minimum requirement based on standard MIL-PRF-28800F.

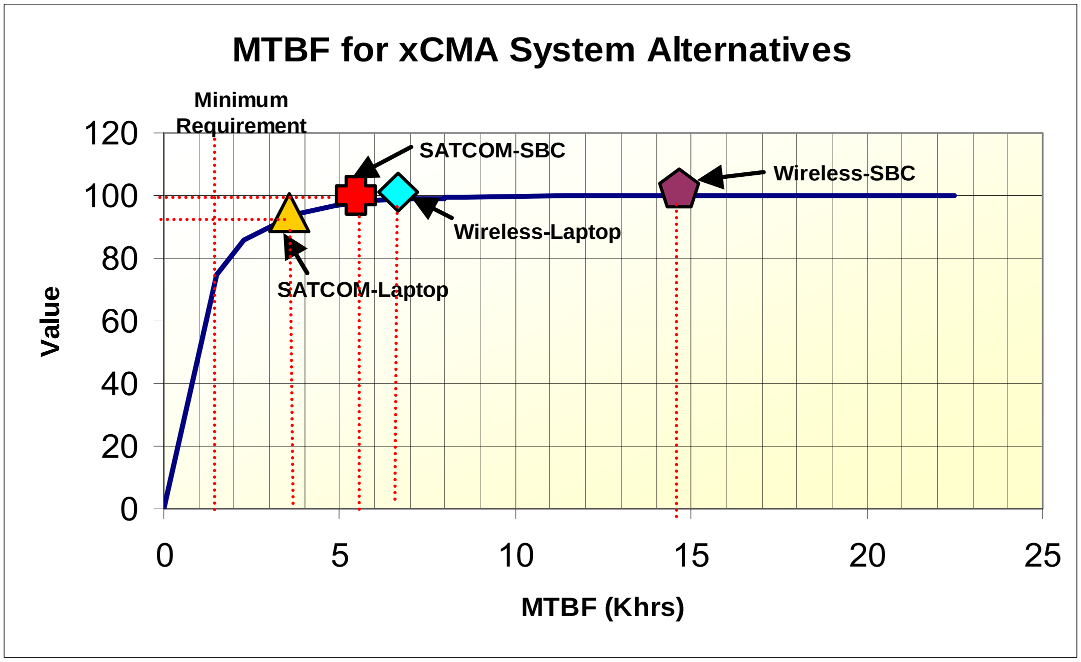

Figure 20. MTBF MAUT Utility for xCMA System Alternatives. The MAUT tool details the relative comparison of the four system options based on mean time between failure.

Throughput was the second evaluation measure examined. Research of similar current systems provided throughput data for each system component as in Table 20. This data was statistically analyzed and the mean value was used in the simulation. The components for each alternative were reviewed. The component with the smallest throughput was used to extract a MAUT value from the utility curve as shown in Figure 21.

Table 20. xCMA System Alternatives Throughput Comparison

Ranking	Alternative	Throughput (Mbps)	Symbol
1 and 2	Wireless – SBC and Wireless - Laptop	3.729	
3 and 4	SATCOM-Laptop and SATCOM-SBC	0.235	

Table 20 summarizes the outcome of the modeling and simulation results for each alternative. These results were based on throughput data from existing systems. The results are ranked according to their resulting throughput. The minimum throughput acceptable was determined to be equal to or greater than 0.128 Mbps based on stakeholder feedback.

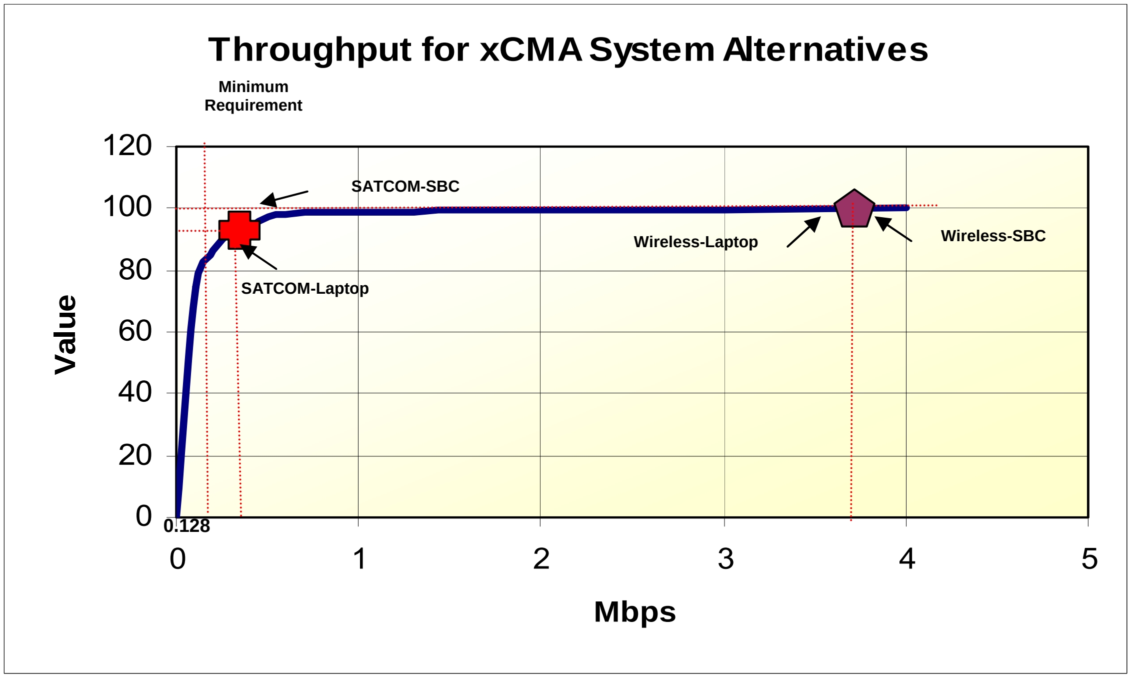

Figure 21. MAUT translation of throughput for the xCMA system alternatives. The MAUT values for throughput are mapped into a 0 to 100 point scale.

Technology Readiness Level (TRL) was the third evaluation measure examined. Research was performed on each of the alternatives and based on the results, the TRL levels were assigned as in Table 21. The MAUT values were extracted from utility curve in Figure 21.

Table 21. xCMA System Alternatives TRL Comparison

Ranking	Alternatives	TRL	Symbol
1 and 2	SATCOM-Laptop and SATCOM-SBC	9	△ ✚
3 and 4	Wireless – SBC and Wireless – Laptop	6	⬟ ◇

Table 21 summarizes the results of the TRLs for each alternative. These results were based on research. To mitigate risk a decision was made to use a system with TRL equal or greater than 6.

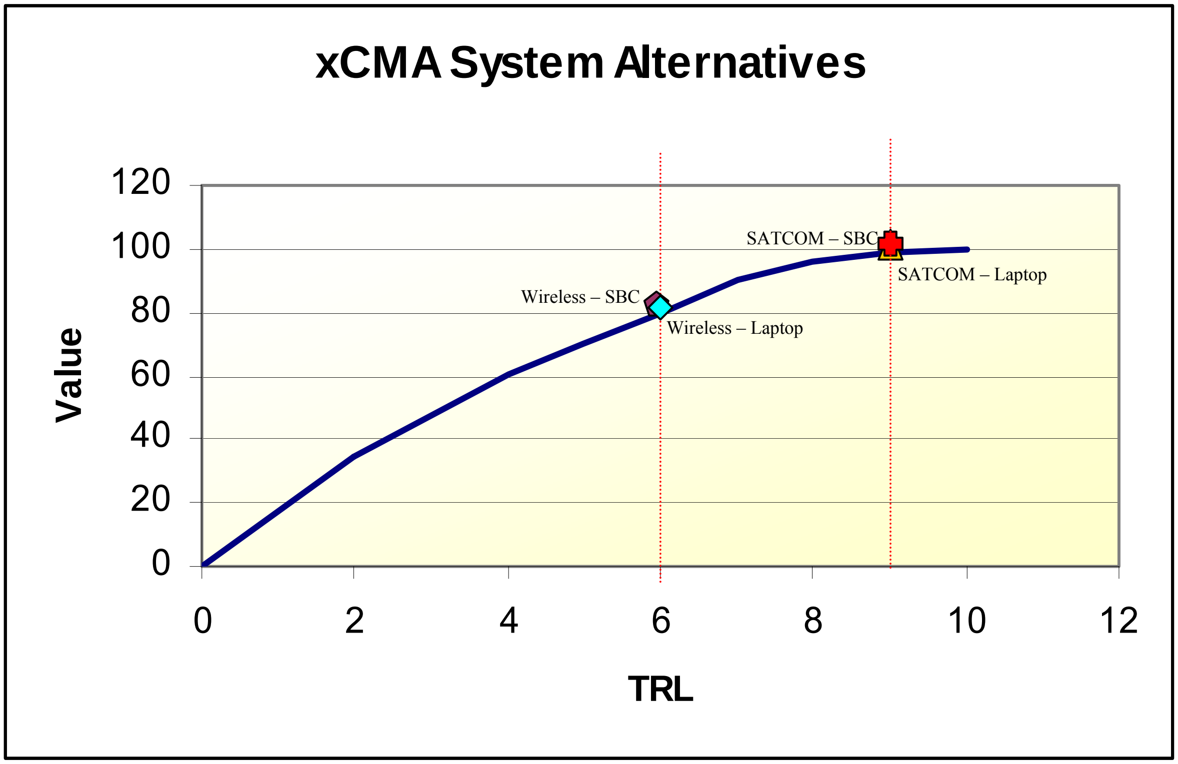

Figure 22. MAUT translation of TRL for the xCMA system alternatives. The MAUT values for TRL are mapped from 0 to 9 into a 0 to 100 point scale.

The Decision Matrix captures and uses weighting factors from the stakeholders to bring out the level of importance of each evaluation measure. The weights of all evaluation measures are normalized to a total value of 100%.

Once the MAUT utilities and global weights are determined, the results from the Raw Data Matrix are translated into the Decision Matrix. The score of each evaluation measure of the xCMA system is extracted from the corresponding MAUT utility curve, as in Figure 20 to Figure 22, to capture the objective score for each of the four xCMA system alternatives. The MAUT scores are then weighted using the corresponding global weight to provide the final score represented in the Decision Matrix. The scores of each xCMA system alternative are then summed to determine the final total score as shown in Table 22.

Table 22. Decision Matrix for the xCMA system

Raw Data Matrix				
Evaluation Measures	Alternatives			
	SATCOM-Laptop	SATCOM-SBC	Wireless-Laptop	Wireless-SBC
System Functional ≤ 4 hours	Y	Y	Y	Y
Connect to CMA ≤ 10 minutes	Y	Y	Y	Y
MTBF ≥ 1500 hrs	91.52%	94.43%	94.76%	97.77%
95% Probability that Throughput ≥ 0.128 Mbps	99.57%	99.57%	99.97%	99.97%

Decision Matrix									
Evaluation Measures	Global Weight	Alternatives							
		SATCOM-Laptop		SATCOM-SBC		Wireless-Laptop		Wireless-SBC	
		MAUT Score	Weighted	MAUT Score	Weighted	MAUT Score	Weighted	MAUT Score	Weighted
System Functional ≤ 4 hours	0.1	100	10	100	10	100	10	100	10
Connect to CMA ≤ 10 minutes	0.1	100	10	100	10	100	10	100	10
MTBF ≥ 1500 hrs	0.25	93	23.25	98	24.5	98	24.5	100	25
95% Probability that Throughput ≥ 0.128 Mbps	0.25	92	23	92	23	100	25	100	25
TRL ≥ 6	0.3	98	29.4	98	29.4	80	24	80	24
Total Value Score			95.65		96.90		93.50		94.00

The Total Value Scores resulted in the SATCOM-SBC system alternative having the highest value at 96.90 out of 100 possible points. The second highest value is 95.65 for the SATCOM-Laptop system alternative. The third alternative, Wireless-SBC, rates lower at 94.00. The Wireless-Laptop system alternative has the lowest score at 93.50. The results from the alternative scoring indicate the SATCOM-SBC option is the recommended solution, however, the results also indicate that all system alternatives exceed the evaluation criteria.

2. Sensitivity Analysis

During the sensitivity analysis process, the evaluation criteria are defined and assessed with respect to each of the alternatives. The evaluation criterion is detailed in the sections below and the value charts are based on MAUT.

System Functional (≤ 4 hours): This evaluation measure is weighted by assigning a numerical value between 0 and 100 to the estimated xCMA system set up time. All four alternatives scored satisfactorily, and met the operational requirements.

Connect to CMA (≤ 10 minutes): This evaluation measure is weighted by assigning a numerical value between 0 and 100 to the estimated time from

xCMA system turn-on to actual connection to the CMA. All four alternatives scored satisfactorily, and met the operational requirements.

Required Throughput (=95%): This evaluation measure is weighted by assigning a numerical value between 0 and 100 to the required throughput percentage; the higher the percentage of throughput above 95%, the higher the score. All four alternatives scored satisfactorily, and met the operational requirements. The alternatives including the Wireless option scored 100.

MTBF (hours): This evaluation measure is weighted by assigning a numerical value between 0 and 100 to the MTBF; the higher the MTBF, the higher the score. All four alternatives scored satisfactorily, and met the operational requirements.

Technology Readiness Level (TRL) (≥ 6): This evaluation measure is weighted by assigning a numerical value between 0 and 100 based on the TRL values of 0 to 9. The SATCOM based systems both scored 98 and the wireless systems scored an 80.

B. RECOMMENDATION

Through the culmination of the efforts of applying the tailored systems engineering process and using the results of the tools and activities leading to the generation of the decision matrix and the sensitivity analysis the resulting recommendation indicates all four options are viable systems and are capable of providing a solution to the problem. The Satellite Communication (SATCOM) with a Single Board Computer (SBC) alternative, however, is the higher ranked configuration for extending CMA to a disconnected node in support of humanitarian efforts. In this approach a SATCOM capability is used as the communications means for connecting to the CMA network. The information from the host system consisting of an SBC, modem/router, power supply, display, and input devices packaged in a ruggedized, transportable container is routed through the modulator demodulator (modem) and then

transmitted by the satellite transmitter to the Node 4 satellite receiver (Node 4 details are to follow). The information from Node 4 is transmitted by a satellite transmitter and received by the system satellite receiver and demodulated for processing by the host system. The Network Interface Card (NIC) provides the system with a unique hardware Media Access Control (MAC) address for system identification. A Commercial-Off-The-Shelf (COTS) Global Positioning System (GPS) receiver is used to provide system Position Location Information (PLI).

C. FUTURE ACTIVITIES

The systems engineering process focuses on technology research, analysis, and solutions. Cost with regards to technology tradeoffs was not performed on the generated alternatives or considered in the decision making. Because all the evaluated alternatives are considered to be viable options, future cost analysis should be conducted.

The current 802.16e range capability lacks the 30 nm requirement by 4.5 miles. One capability proposed in the 802.16m standard states improved range, which has yet to be defined. It is an assumption that the proposed increase in range will meet the 30 nm requirement. The standard is scheduled to be completed by 2009. The 802.16m technology is a viable future option, once the TRL matures and systems become readily available.

The SBC requires further integration and this was not addressed in the evaluation of the system. Integration effort in this alternative could lead to additional technology requirements and costs. These considerations are disadvantages for this particular alternative. Therefore, the laptop solution may be a more viable current implementation.

APPENDIX A. STATEMENT OF WORK

Comprehensive Maritime Awareness for Non-CMA Connected Nodes

Scope:
This task investigates the extension of Comprehensive Maritime Awareness to non connected nodes to facilitate continued information sharing. The specific focus will be on the architecture required to ensure that previously non-CMA connected nodes and end users are active participants in CMA. The following will be the primary scenarios used for validating the candidate architecture.

- Non-CMA Connected Vessel - Connectivity of planned, non operative CMA node
  - Coast Guard small boat that doesn't have capability to do (fusion, MDA CONOPS objectives)
  - Red Cross type ship; Navy Hospital Ship
  - Commercial ship

Assumptions:
The following assumptions are made regarding this effort.

- CMA systems exists and are fully operational (Nodes 1 through Node 4)
- Node 4 will use existing fusion and operational capabilities to enable disadvantage node connection to the CMA. It will be responsible for its own information and data flow to the CMA as well as the info from the previously non-connected Node 5.
- Connections will involve unclassified data only
- Regional gateway will be MHQ with MOC (Node 3)
- Connectivity between Node 4 and Node 5 will be provided by a "black box" connectivity system.

Guidance for Architecture:

- Use CMA OV-1 and OPNAV N6 OV-1 (from MDA N6 Brief) as a high-level view and assumption to their architecture development.
- Also use MHQ with MOC OV-1
- Size, power and weight constraints similar to small vessels and assumes max distance to node 4 of 30 nm

CDD Guidance:
Assume CMA capabilities are there. Develop CDD to support CMA Node 4 and Node 5, as defined above, under the Fleet CMA CONOPS/Architecture.

- The work product will be an appendix and will be delivered in lieu of Chapters 4 & 5 of the Project Report

- The ICD requirement for the MDA CDD was fulfilled with the following documents:
- National CONOPS to Achieve Maritime Domain Awareness
- Fleet CONOPS for Maritime Domain Awareness
- Fleet MHQ/MOC CONOPS
- GMII CONOPS
- CMA Implementing Directive (Joint Requirements Oversight Council Approved)
- CMA CONOPS

CDD Guidance:
Definitions:
The following definitions will be used for Node 4 and Node 5 for this effort.
Node 5: Vessel with sensor capabilities (none to extensive) and having either limited or no CMA connectivity

Node 5: A Node 5 participant is a user or vessel with sensor capabilities varying from none to extensive, that does not have a direct connection to the existing CMA network. This node will be limited to sending request for area information, providing aperiodic manual sensor or visual information and receiving updates from Node 4. The following characteristics apply:

- No data fusion capability
- Limited sensor data available
- Provides input into CMA network via node 4 connection
- Receives guidance from CMA network regarding mission specific info

Node 4: The Node 4 asset will be the gateway between the Node 5 and the CMA network. It will be provide connectivity between Node 5 and all other CMA nodes. It will be capable of :

- Collecting CMA data, including data from Node 5 and providing it to the CMA network
- Fusing maritime data/info, CMA and Node 5 using existing CMA fusion capabilities
- Assessing threats; alerts
- Sharing threats & picture; including providing the UDAP for Node 5

Technical Requirements:
Statement of Work:

- **Characterization of the Problem Space**: the identification of current system ("as is") and the deficiencies as well as constraints inherent in the operational environment in order to characterize, understand and bound the problem space. The project team will identify and translate CMA functions from the Fleet MDA CONOPS, National MDA CONOPS, and the CMA CONOPS into system engineering structures ("to be" concepts, data models, and architecture functions, requirements, solutions) necessary to develop the node 4 and node 5 connectivity

concept. The project team will evaluate the functions, requirements and architectures in support of the integration of CMA requirements.

1. **Functional Representation And Decomposition**: the representation of system concepts through functional description and decomposition as well as system architecting (DoDAF models) and simulation. Develop representations, models, and methods to express automated resource collaboration concepts and information sharing solutions in the context of the CMA architecture and domains. The project team will develop a system model and architecture to evaluate the performance of the proposed architecture.

2. **Analysis of Key Capabilities**: the identification and evaluation of technologies and research areas key to the integration of Nodes 4 and 5 into the CMA concept.

3. **Deliverables:**
    a. **Project Report –** Will include chapters 1-5.
    b. **In Progress Review –** Status review provided end of Quarter 2.
    c. **Final Presentation**

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APPENDIX B. INPUT/OUTPUT ANALYSIS

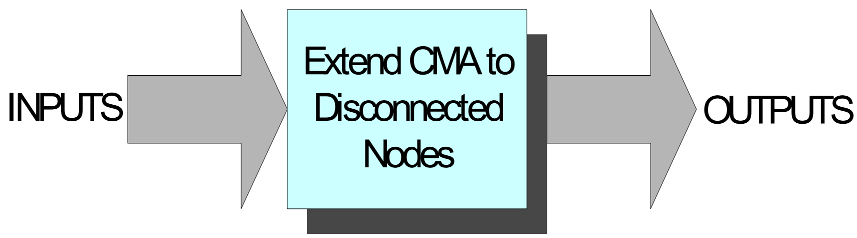
The Input/Output analysis was performed as a first step in defining the needs and constraints for the xCMA system. The complete input/output analysis is shown in Figure B-1. The purpose of this diagram is to indicate the flow of information between the inputs and the transformation of those inputs into outputs for the xCMA system. The Input/Output analysis concentrates on defining the requirements and not the functions of the system or functional requirements. The required inputs were broken down into controllable and uncontrollable inputs and the related outputs were intended and unintended, or by-products. Intended inputs are those inputs that are determinable or controlled and the unintended inputs cannot be controlled. Desired outputs are shown as intended outputs and the by-products are identified as undesired outputs. The desired outputs are the main purpose for the xCMA system and ultimately define or meet the needed requirements. During the input/output analysis, constraints were identified while still meeting the requirements of the effective need statement.

Controllable

- Fused CMA Information
- UDAP
- Warnings/Alerts
- Position Information
- System Authentication
- Bandwidth
- Local Awareness

Intended

- Consolidated CMA Information
- UDAP
- Warnings/Alerts for Area of Interest
- Position Information
- Validated Authentication
- Scalable bandwidth on Demand



Uncontrollable

- Incorrect Information
- Weather
- Environment
- Jamming/Meaconing/Malicioius attacks
- Security Violation (unintended classified info)

By-Product

- Incorrect Information
- Too much Information
- Unusable Information
- Loss of Information
- Security Violation (unintended classified info)

Figure B-1. xCMA Input-Output Analysis. The Input/Output analysis was performed as a first step in defining the needs and constraints for the xCMA system. The purpose of this diagram is to indicate the flow of information between the inputs and the transformation of those inputs into outputs for the xCMA system.

APPENDIX C. FUNCTIONAL FLOW BLOCK DIAGRAM (FFBD)

In order to perform a basic functional decomposition of the system a FFBD was constructed. This FFBD decomposed each level, or basic function to better understand how the information flows through the proposed system. Inputs to the system enter from the left and exit to the right as outputs. The functional flow block diagram is shown in Figures C-1 through Figure C-7. Figure C-1 shows the main functions of the proposed xCMA system. Figure C-2 shows the flow of information for the Connect with CMA function. Figure C-3 shows the flow of information for the Provide Collaboration function and Figure C-7 shows the flow of information for the Manage Information function. The Provide Collaboration function has several subsets, or subnodes, which are identified as Receive, Send, and Display Information and are shown in Figure C-4, Figure C-5 and Figure C-6, respectively.

"And" connectors are used to show parallel functions that are accomplished and "Or" connectors are used where the flow of information can proceed any one function. The flow of information is always shown to go from left to right. Decomposition of functions is shown as references.

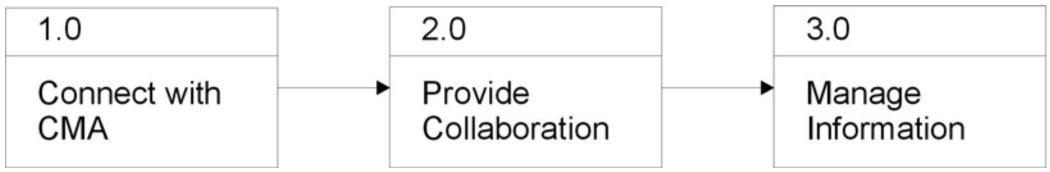


Figure C-1. xCMA Main Functions Functional Flow Block Diagram. This figure depicts the top level functions of the xCMA system in a functional flow block diagram format

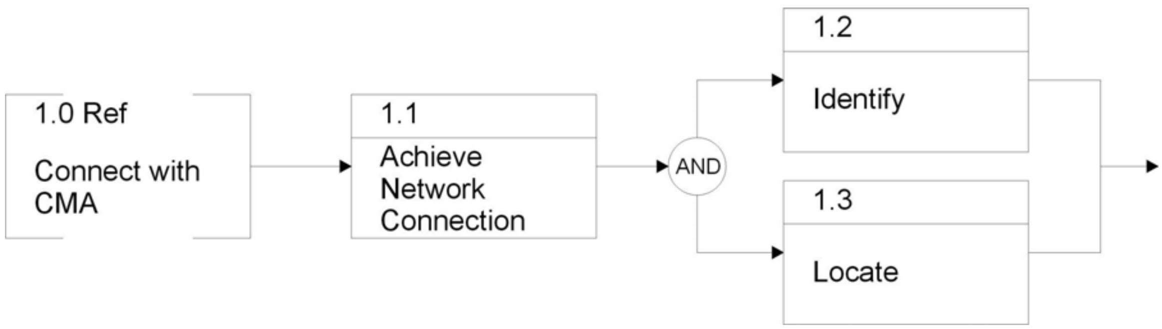


Figure C-2. xCMA Connect with CMA Functional Flow Block Diagram. This figure depicts the Connect with CMA functions of the xCMA system in a functional flow block diagram format

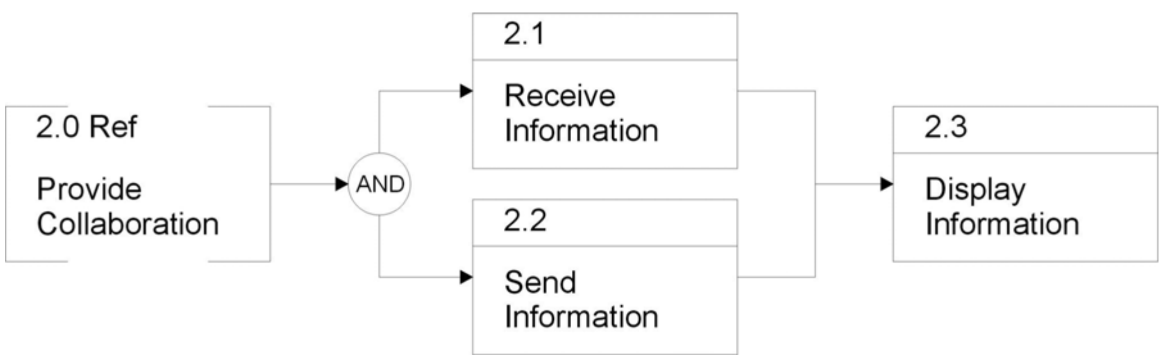


Figure C-3. xCMA Provide Collaboration Flow. This figure depicts the Provide Collaboration Flow in the xCMA system in a functional flow block diagram format.

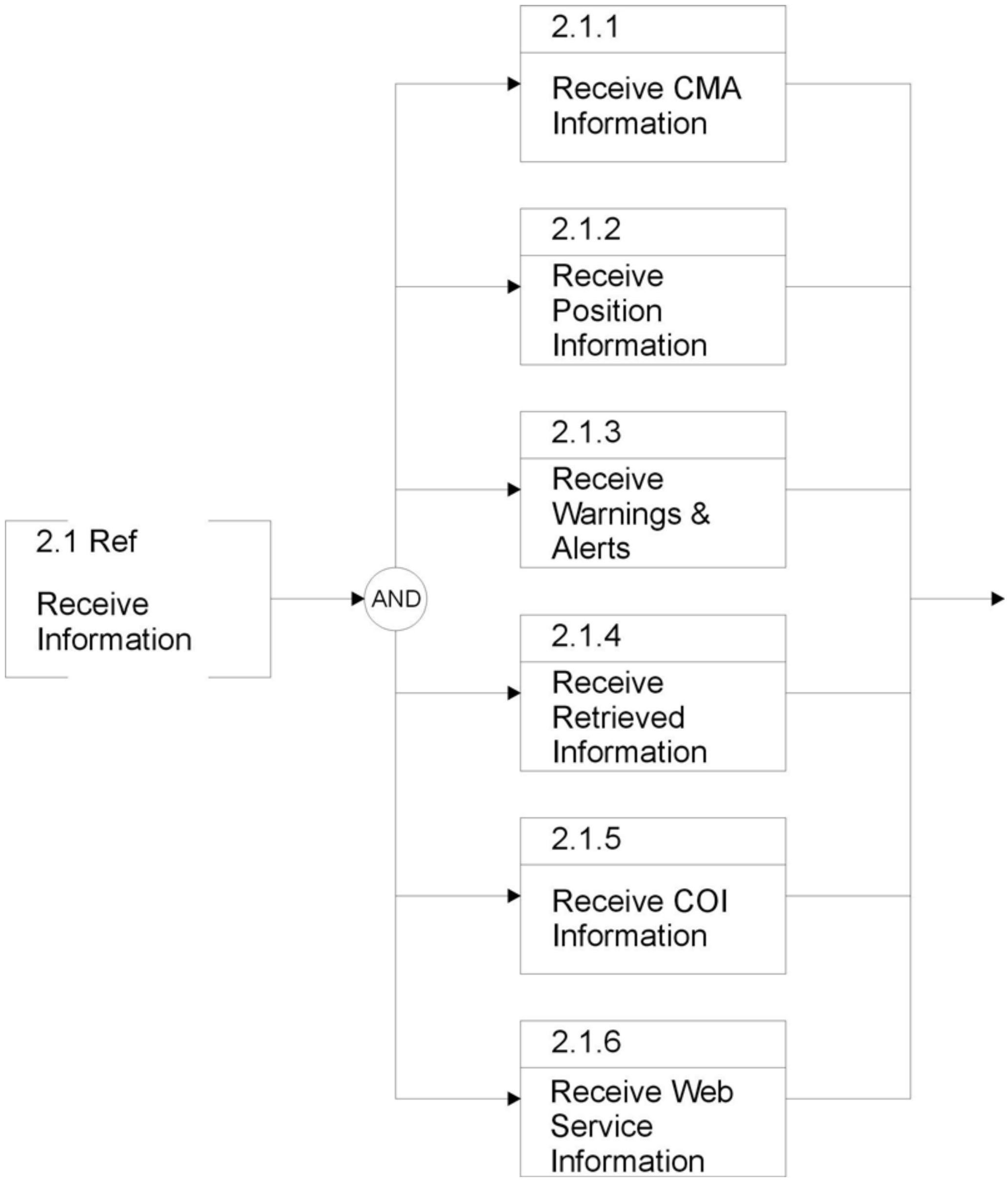


Figure C-4. xCMA Subnode Receive Information Functional Flow Block Diagram. This figure depicts the Receive Information portion of the xCMA system in a functional flow block diagram format.

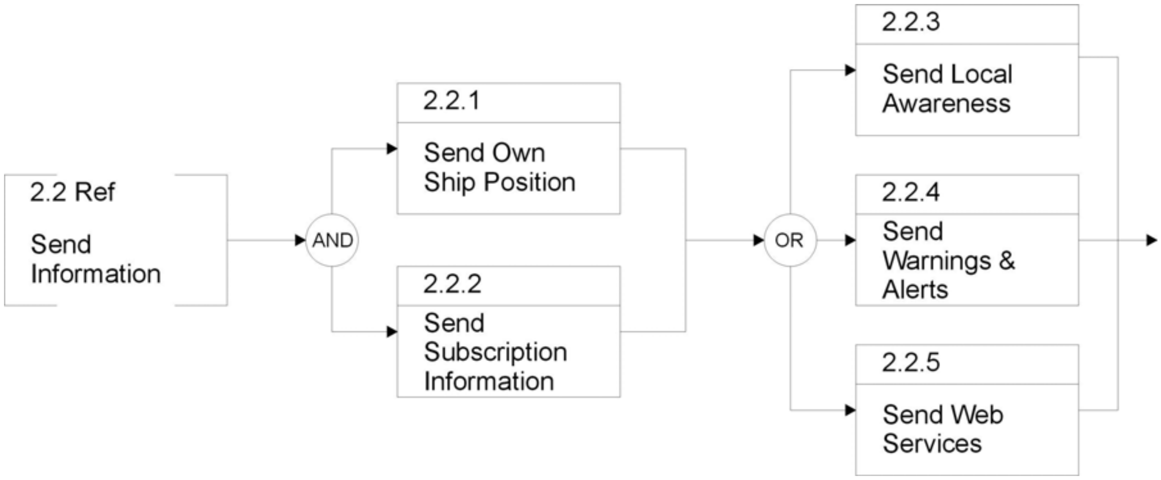


Figure C-5. xCMA Subnode Send Information Flow. This figure depicts the Send Information portion of the xCMA system in a functional flow block diagram format.

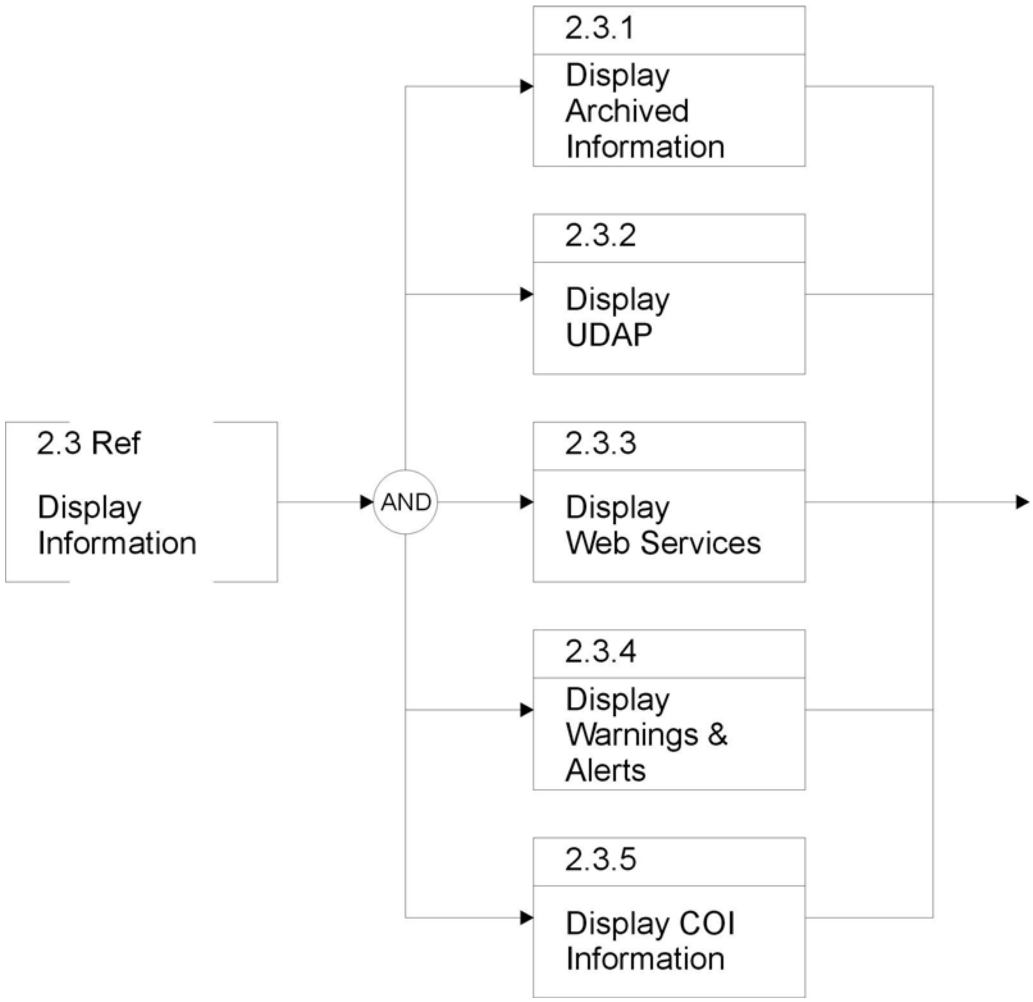


Figure C-6. xCMA Subnode Display Information Functional Flow Block Diagram. This figure depicts the Display Information portion of the xCMA system in a functional flow block diagram format.

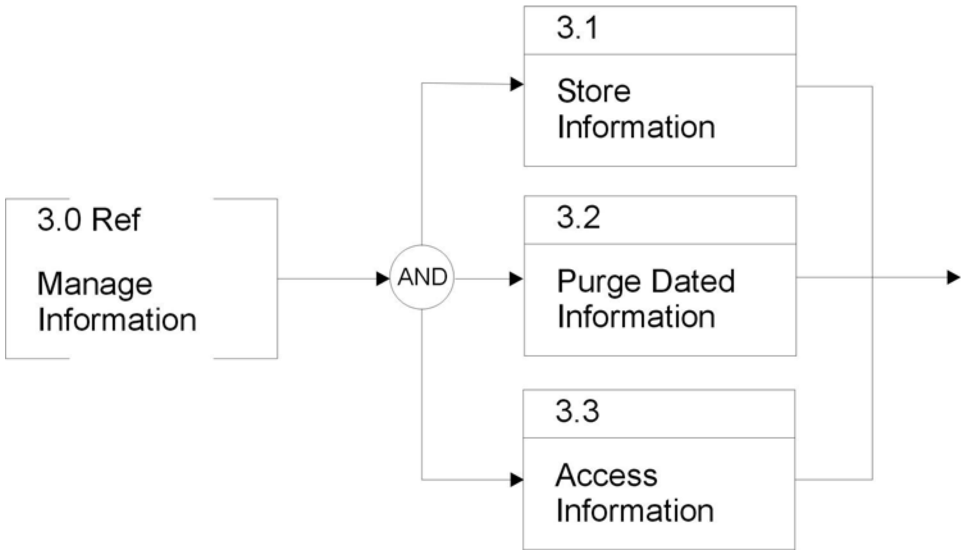


Figure C-7. xCMA Manage Information Functional Flow Block Diagram. This figure depicts the Manage Information portion of the xCMA system in a functional flow block diagram format.

APPENDIX D. IDEF0

A functional model of the xCMA system was constructed using IDEF0. The IDEF0 model structurally reflects the system functions and shows the flow of information connecting these functions. The basic functions used in the IDEF0 model were previously identified in the FFBD. The IDEF0 model identifies input data and the processing as well as analysis that takes place as part of the model. Identified are also inputs that are required from the User at the disconnected vessel, information that is sent via the xCMA system to the gateway node, and information that is received via the gateway node. This aids in determining the requirements for processing and receiving of the various kinds of data as well as operator interfaces that are incorporated into the design. The various kinds of information that transfer between the xCMA system and the gateway node are then used to calculate requirements for bandwidth and for optimization of the overall system. The model further aids in identifying requirements that satisfy the effective need and validation of these requirements through stakeholder inputs. The complete IDEF0 model is shown on Pages D3 through D10.

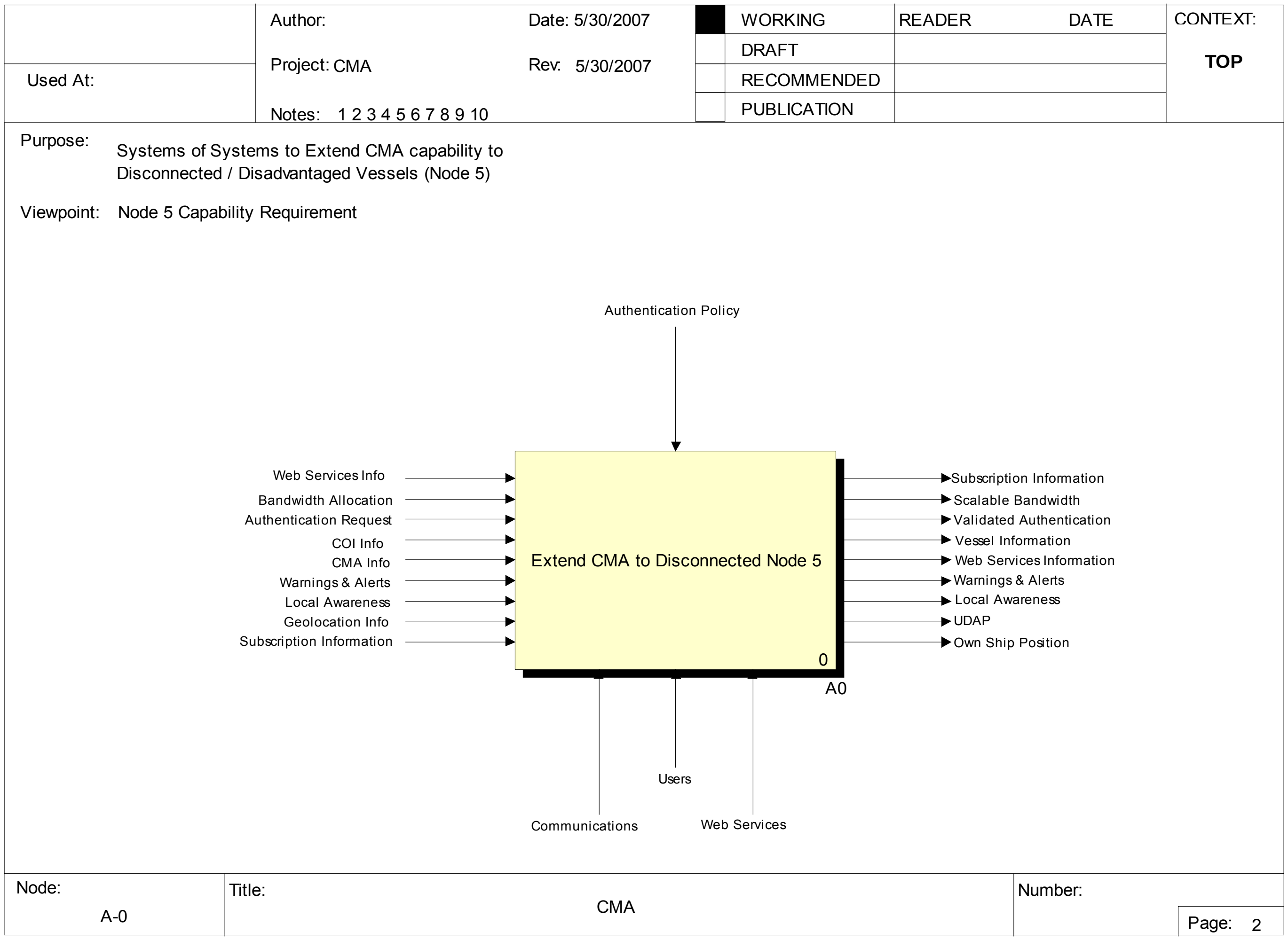


Figure D-1. xCMA Context Diagram (A-0). The A-0 diagram shows the external interface for the xCMA Node 5.

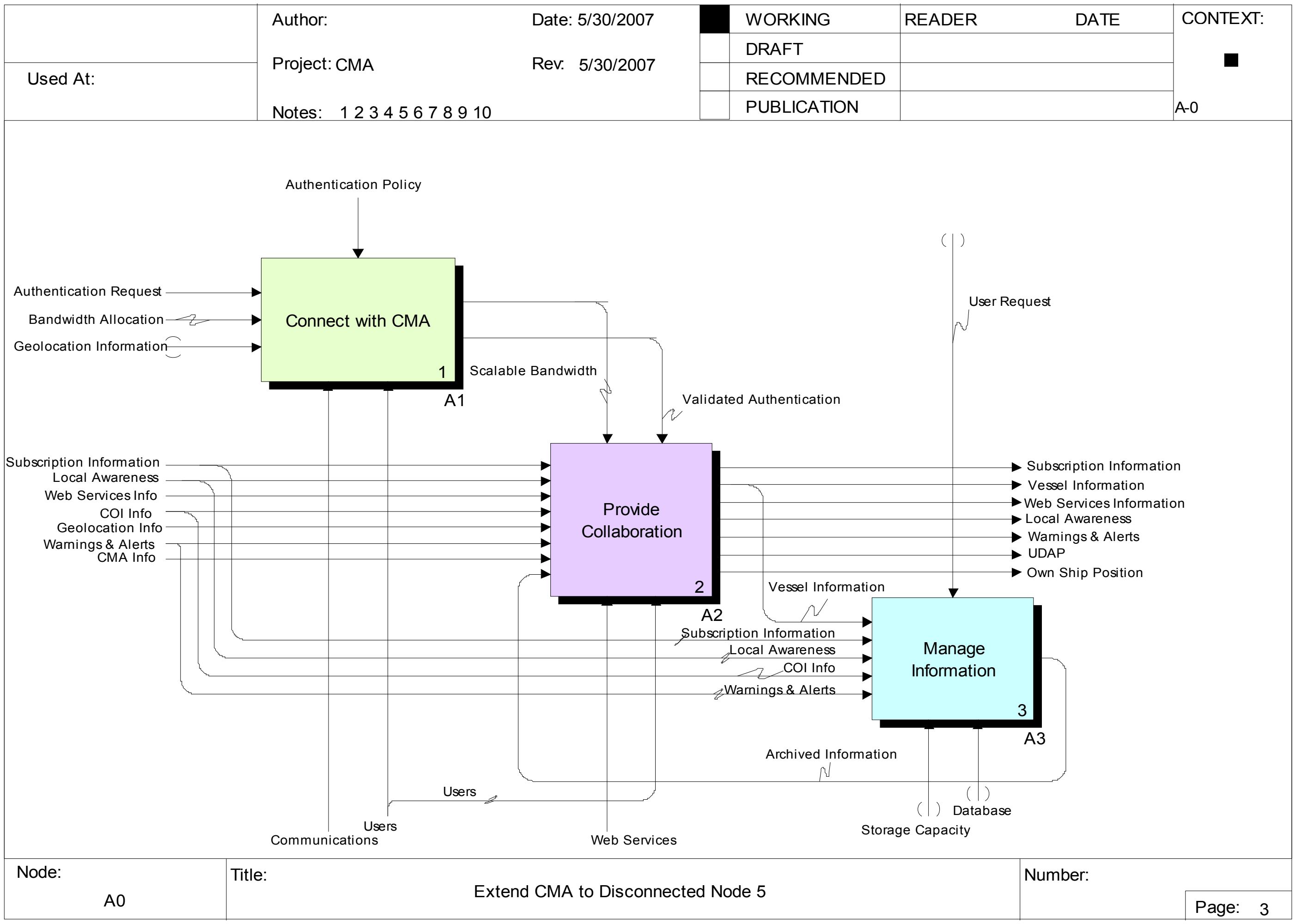


Figure D-2. Extend CMA to Disconnected Node 5 (A0). The A0 diagram shows the detailed interface of the CMA to Node 5.

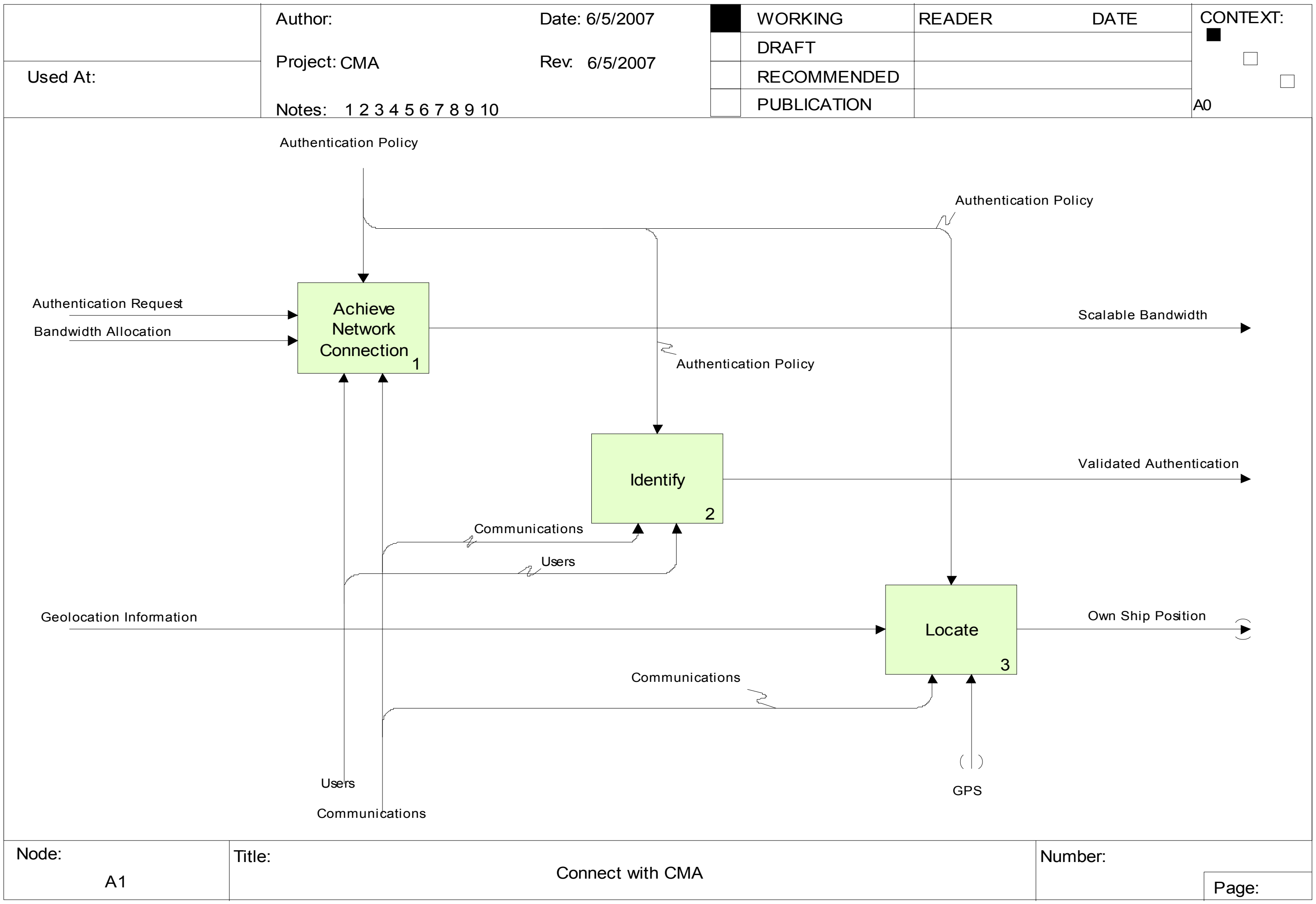


Figure D-3. xCMA Connect with CMA (A1). The A1 diagram details the interface between the subfunctions of the Connect with CMA function.

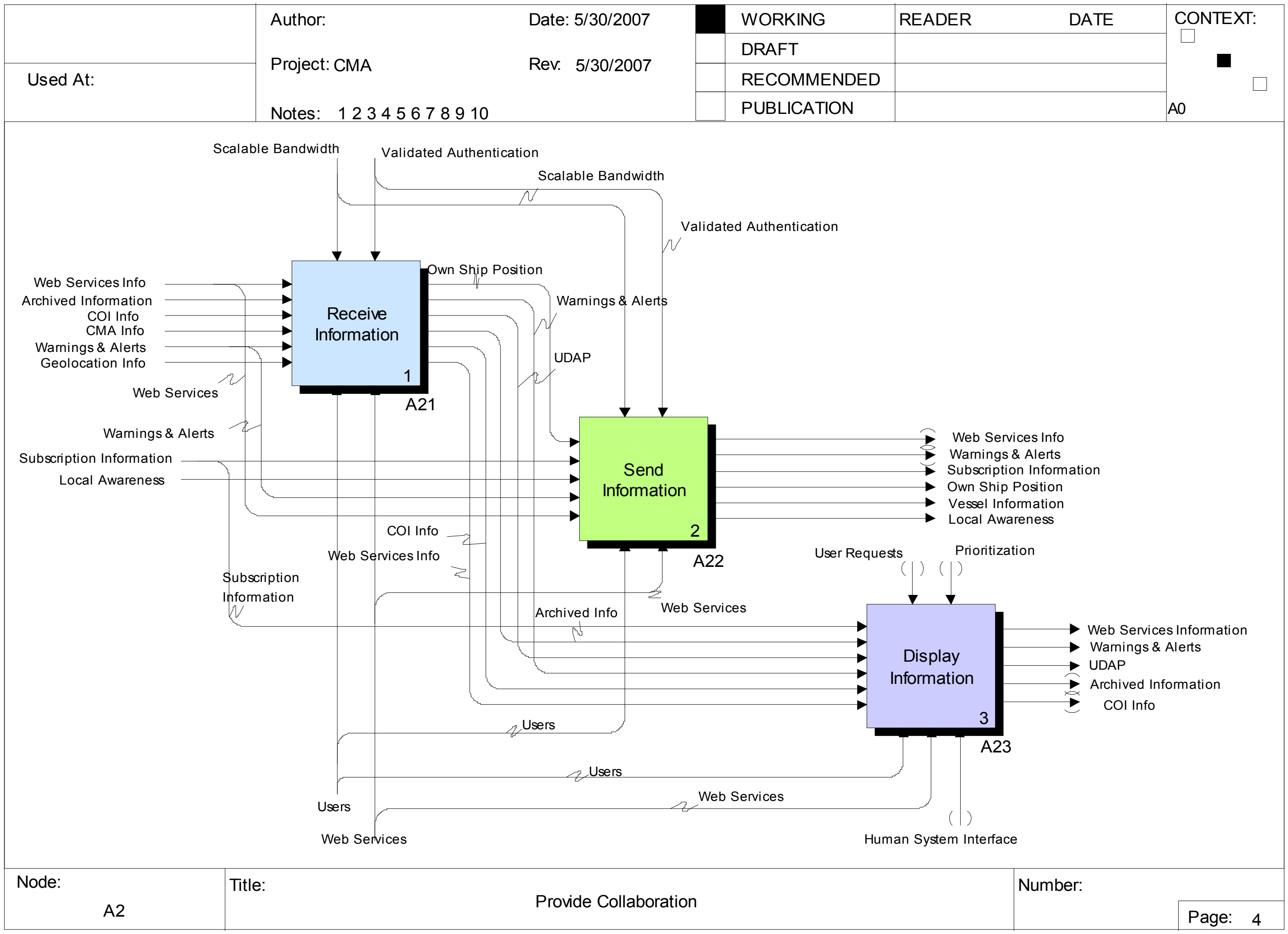


Figure D-3. Provide Collaboration within xCMA system (A2). The A2 diagram details the interface between the main functions of the xCMA system.

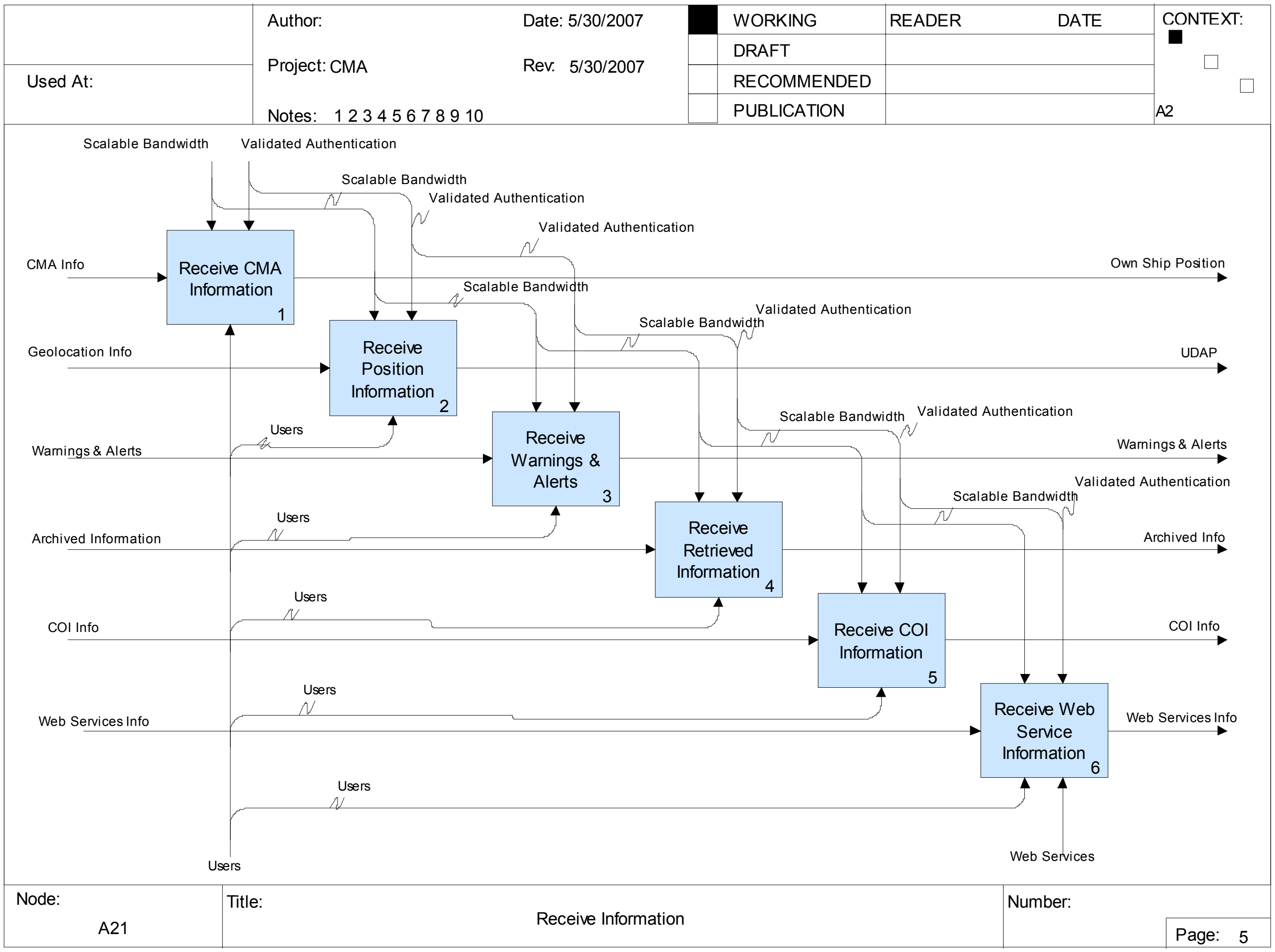


Figure D-4. Receive Information (A21). The A21 diagram drills down into the subfunctions of receive information function.

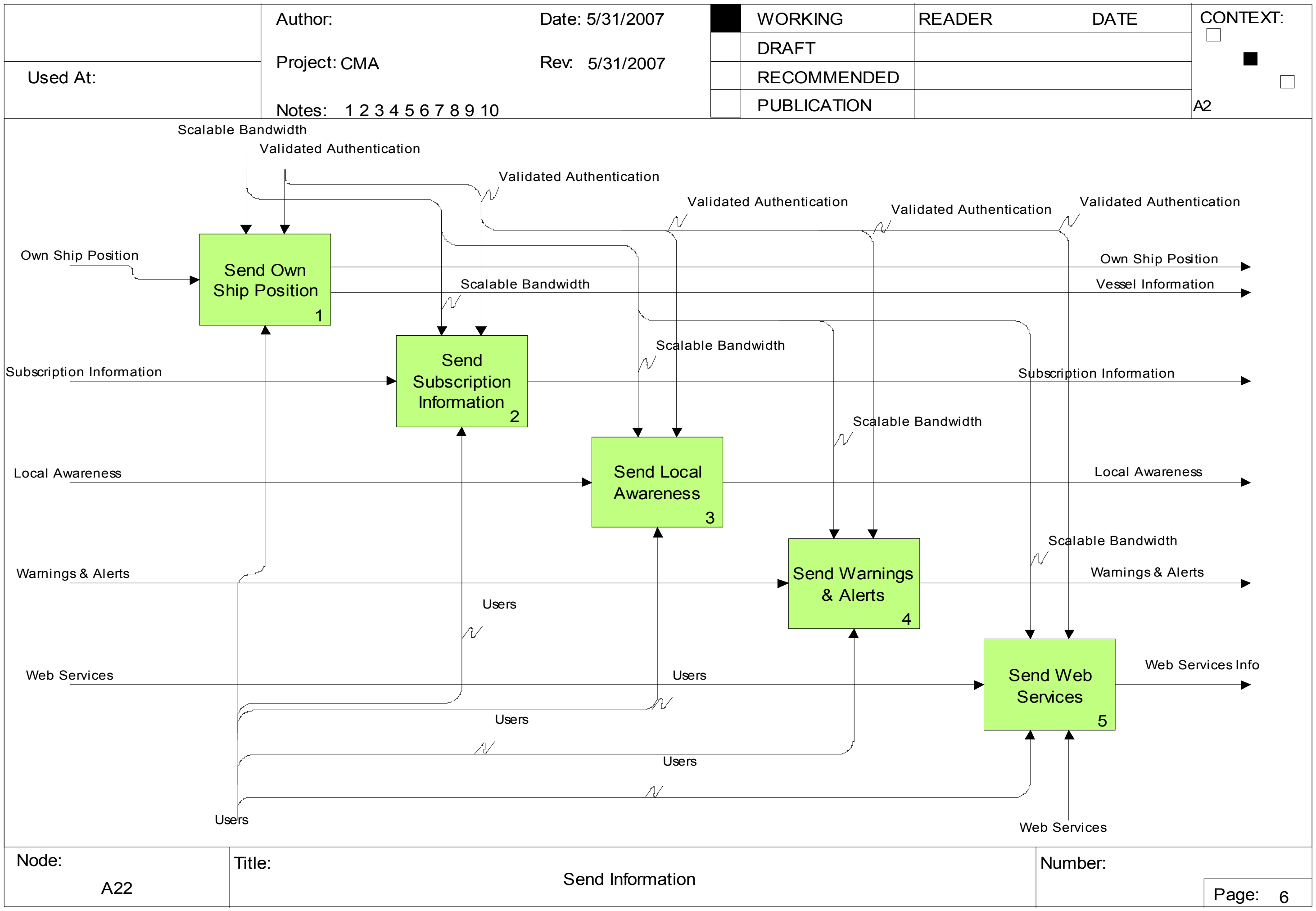


Figure D-6. xCMA System Send Information (A22). The A22 diagram drills down to the subfunctions of the Send Information function.

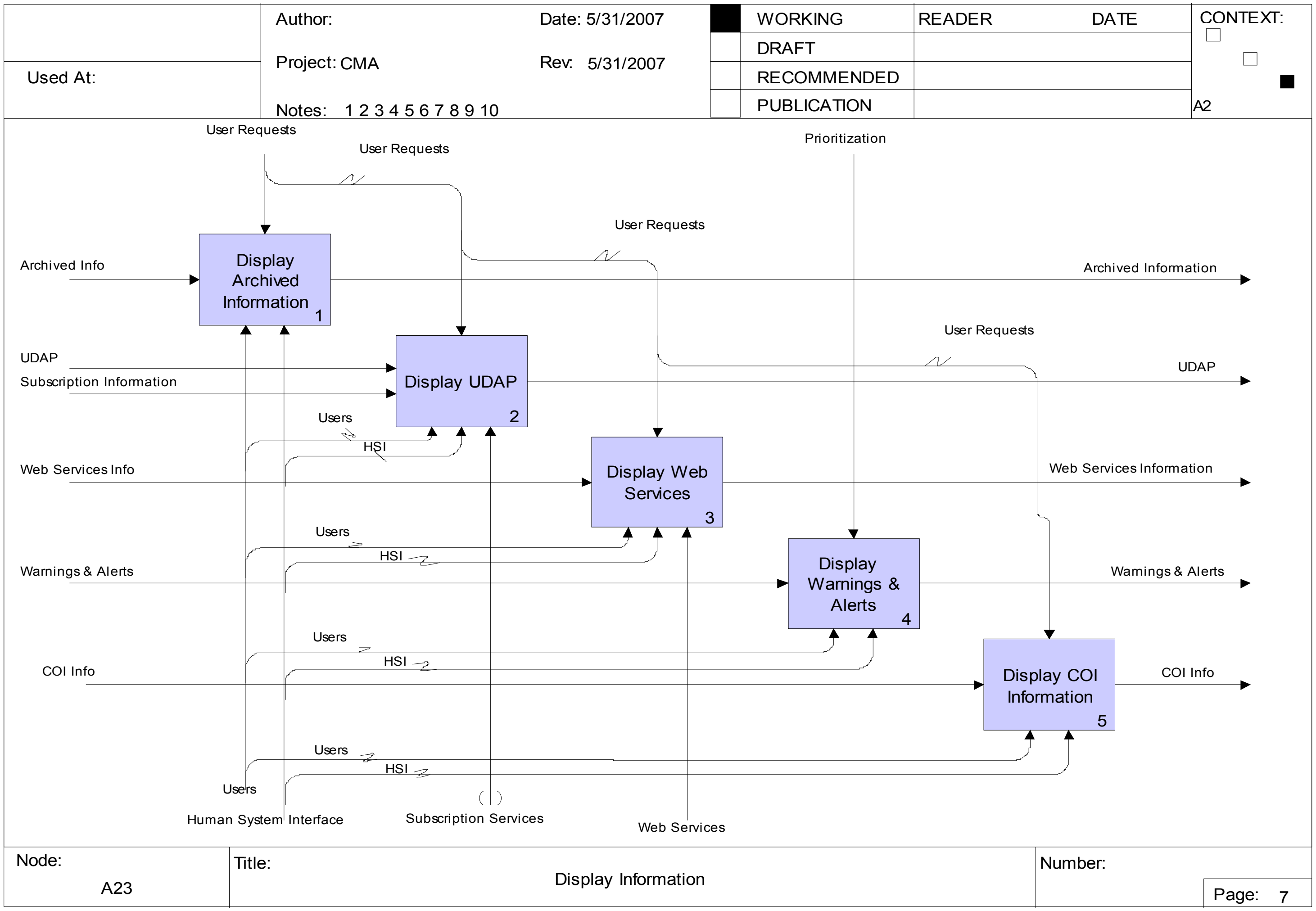


Figure D-7. xCMA System Display Information (A23). The A23 diagram drills down to the subfunctions of the Display Information function.

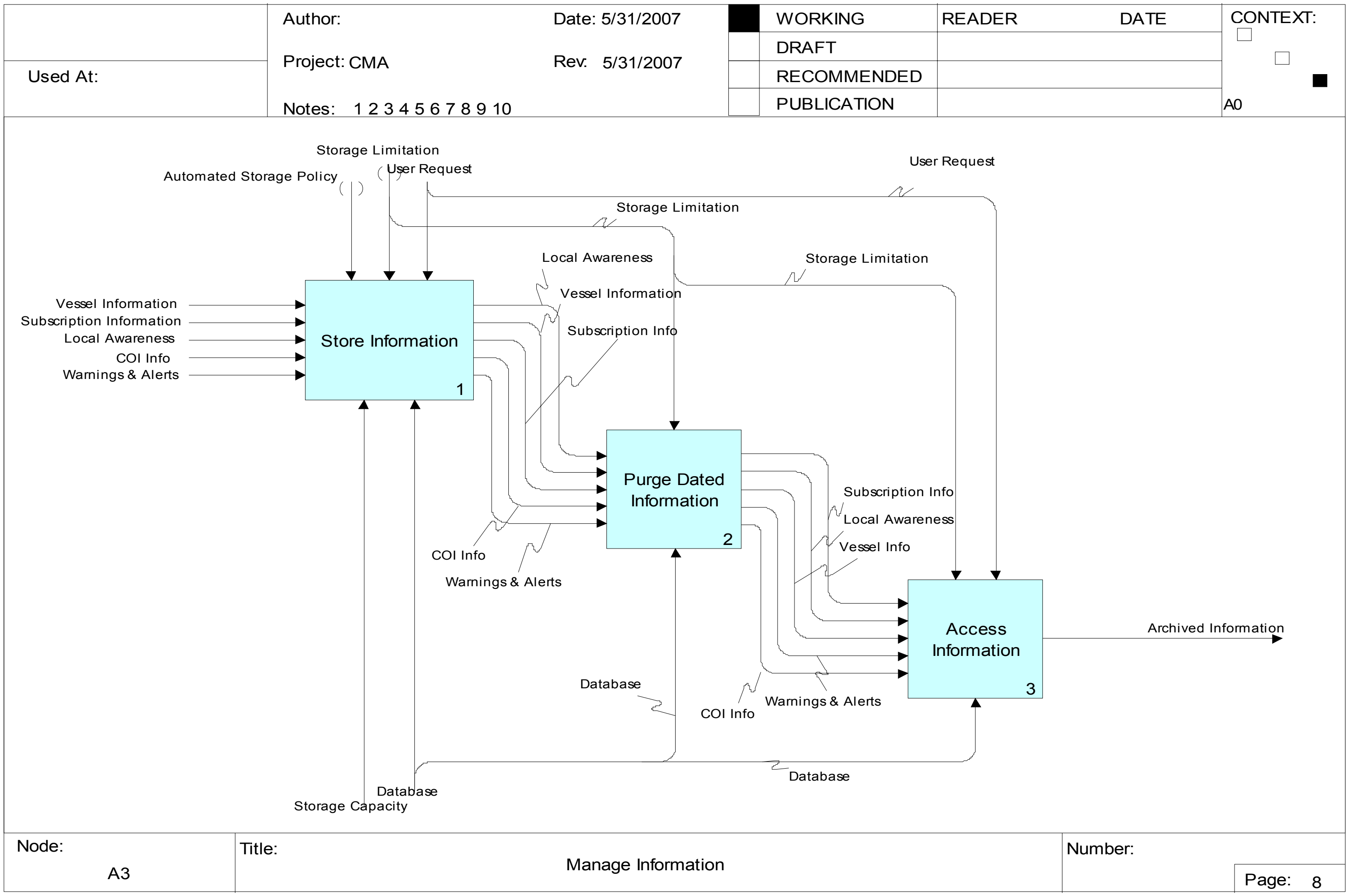


Figure D-7. xCMA Manage Information (A3). The A3 diagram drills down to the subfunctions of the Manage Information function.

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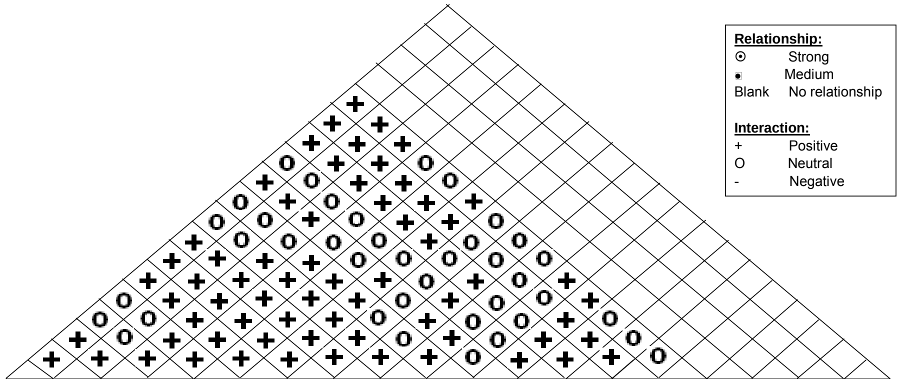
APPENDIX E. QUALITY FUNCTIONAL DEPLOYMENT

In an effort to facilitate responsiveness to customer requirements, a QFD diagram was performed. The development of the QFD ensures that all the customer requirements are identified and applied in the most appropriate manner to address the problem. The QFD results aided in a common understanding of requirements between all the stakeholders and identified the most important requirements to be met by the xCMA system.

Once the QFD relationships were established, weighting factors were assigned to each of the requirements. The weighting factors identified the requirements that were used as MOEs for the system performance. The QFD also presented the customer requirements in engineering terms.



Relationship:
⊙ Strong
• Medium
Blank No relationship

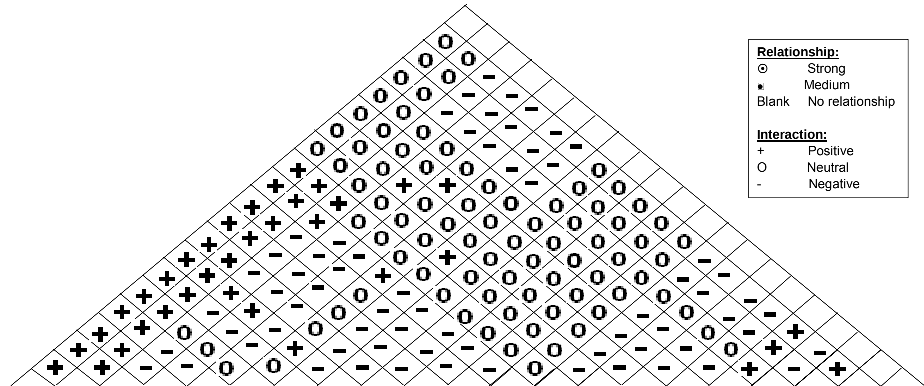
Interaction:
\+ Positive
O Neutral
\- Negative

System Level Requirements

Customer Requirements | Relationship

Customer Requirements	Connect with CMA	Receive data and information	Transmit data and information	Display data and information	Manage Data and information	Provide unclassified collaboration	Provide open architecture design	Provide plug and play interface	Provide Graphical User Interface	Provide computer based training	Provide remote trouble-shooting and corrective action	Provide O-D preventive and corrective maintenance paradigm	Provide Ao (0.9)	Provide MTBF (1500 hrs)	Operating Radius < 30 nmi				
Provide secure connection of Node 5 to CMA Node 4	⊙	⊙	⊙										⊙	⊙	⊙				
Provide unclassified warnings and alerts	⊙	⊙		⊙	•	⊙			•	•			⊙	⊙	•				
Provide unclassified UDAP	⊙	⊙		⊙	•	⊙			•	•			⊙	⊙	•				
Provide access to all required info	⊙	⊙		⊙	•	⊙			⊙				⊙	⊙	•				
Provide access to web services	⊙	⊙		⊙	•	⊙			⊙		•		⊙	⊙	•				
Provide capability to store data and info		•	•	•	⊙														
Allow graceful system degradation	⊙	⊙	⊙	⊙	⊙	⊙	•	•	•	•			⊙	⊙					
Provide intuiative human system interface		⊙	⊙	⊙	⊙	⊙		⊙	⊙	⊙	⊙								
Provide scalable system - maximize interoperability	⊙			⊙	•		⊙	⊙	⊙	•	•	•							
Provide flexible system - allow user display customization				⊙		⊙		⊙	⊙	•									
Provide accurate data and info		⊙	⊙	⊙	•	•													
Provide accurate local data and info		⊙	⊙	⊙	•	•													
Provide timely data and info	⊙	⊙	⊙	⊙	⊙	•									•				
Provide a portable system -- size, weight?							•	•	•	•	•								
Provide reliable system -- MTBF = 1500 hrs	⊙	⊙	⊙	⊙	⊙	⊙					•	•	⊙	⊙					
Provide flexible system operator training										⊙									
Provide flexible system maintainer training										⊙	•	•							
Allow system trouble-shooting and corrective action										⊙	⊙	⊙	⊙						
Total Influence Score	9	11.5	7.5	12.5	8.5	9.5	2	4	7	7	4.5	2.5	8	7	3.5	0	0	0	0

Figure E-1. QFD Representation of System Level Requirements. This QFD depicts the interactions between the system level requirements and relationship between the system level requirements and customer requirements.



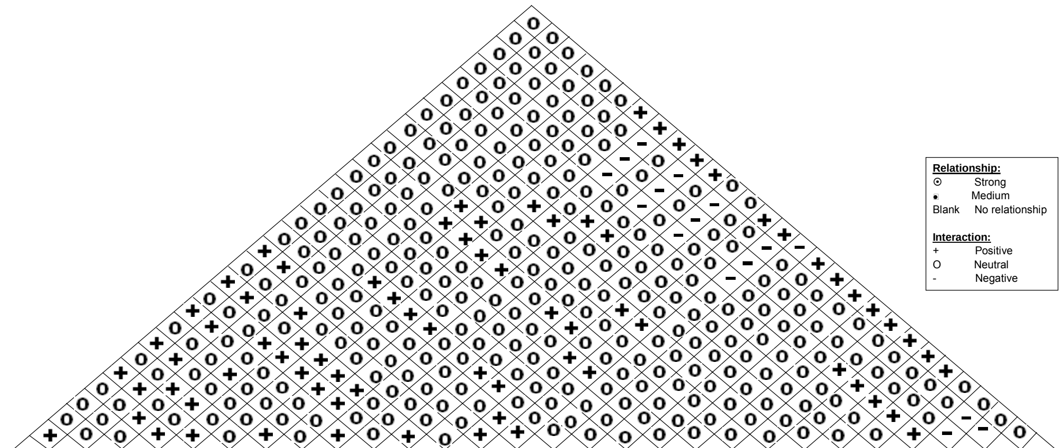
System Functions and Subfunctions

System Level Requirements

System Level Requirements	Connect With Node 4: Identify	Connect With Node 4: Locate	Receive CMA Info	Receive Warnings and Alerts	Receive COI Info	Receive Position Info	Receive Web Services Info	Send Subcription Info	Send Local Awareness	Send Warnings and Alerts	Send Web Services Info	Send Own Ship Position Info	Display MDA UDAP	Display Web Services	Display Warnings and Alerts	Display COI Info	Display Archived Info	Store Info	Purge Info	Access Info	
Connect with CMA	⊙	⊙	⊙	⊙	⊙	⊙		⊙	⊙	⊙	⊙	⊙									
Receive data and information	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙			•	⊙	•	•	•	•		•			
Transmit data and information	⊙	⊙						⊙	⊙	⊙	⊙	⊙									
Display data and information			•	•	•	•	•						⊙	⊙	⊙	⊙	⊙	•			
Manage Data and information			•	•	•	•	•	•	•	•	•	•	•	•	•	•	⊙	⊙	⊙	⊙	
Provide unclasssified collaboration	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	•	•	•	•					
Provide open architecture design													•	•	•	•	•	•			
Provide plug and play interface	•	•											•	•	•	•	•	•			
Provide Graphical User Interface													⊙	⊙	⊙	⊙	⊙				
Provide computer based training	•	•	⊙	⊙	⊙	•	•	⊙	⊙	⊙	⊙		⊙	⊙	⊙	⊙	⊙				
Provide remote trouble-shooting and corrective action	⊙	⊙	•	•	•	•	•	•	•	•	•	•	•	•	•	•					
Provide O-I-D preventive and corrective maintenance paradigm																					
Povide Ao (0.9)	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	
Provide MTBF (1500 hrs)	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	
Operating Radius < 30 nmi	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙	⊙					

Relationship

Figure E-2. QFD Representation of System Functions and Subfunctions. This QFD depicts the interactions between the system functions and subfunction elements. Also, the QFD shows the relationship between the system level requirements and system functions and subfunctions.



Relationship:
⊙ Strong
• Medium
Blank No relationship

Interaction:
\+ Positive
O Neutral
\- Negative

System Functions and Subfunctions \ Evaluation Measures	Network Up Time	Network Connectivity MTBF	Identification Accuracy	Location Accuracy +/- 5m	CMA Data Received Accuracy	CMA Data Availability	Incoming Warnings And Alerts Accuracy	Incoming Warnings And Alerts Availability	COI Data Accuracy	COI Data Availability	Geolocation Data Accuracy +/- 5m	Geolocation Data Availability	Web Services Data Accuracy	Web Services Availability	Response In Sending Vessel Info < 10s	Subscription Info Sent Correctly	Local Info Sent Correctly	Warnings And Alerts Sent Correctly	Web Services Sent Correctly	Own Ship Position Info Sent Correctly	Displaying UDAP Correctly	Displaying Web Services Correctly	Displaying Alerts And Warnings Correctly	Display COI Info Correctly	Display Archived Info Correctly	Store Nominal Mission Data	Sort/Search Time < 10s	Retrieve Time < 10s	Network Bandwidth > TBD Kbps
Connect With Node 4: Identify	⊙	⊙	⊙			⊙		⊙		⊙		⊙		⊙	⊙														
Connect With Node 4: Locate	⊙	⊙		⊙		⊙		⊙		⊙	•	⊙		⊙	⊙														
Receive CMA Info	⊙	⊙		•	⊙	⊙					•	•				⊙				•									⊙
Receive Warnings and Alerts	⊙	⊙		•			⊙	⊙			•	•				⊙				•									•
Receive COI Info	⊙	⊙		•					⊙	⊙	•	•				⊙				•									⊙
Receive Poisition Info	⊙	⊙		⊙							⊙	⊙																	•
Receive Web Services Info	⊙	⊙											⊙	⊙		•			•										⊙
Send Subcription Info	⊙	⊙									•	•				⊙				•									•
Send Local Awareness	⊙	⊙															⊙												⊙
Send Warnings and Alerts	⊙	⊙																⊙											•
Send Web Services Info	⊙	⊙												⊙					⊙										⊙
Send Won Ship Position Info	⊙	⊙									⊙	⊙								⊙									•
Display MDA UDAP																•					⊙					⊙	•	•	
Display Web Services																						⊙							
Display Warnings and Alerts																•			•				⊙						
Display COI Info																								⊙					
Display Archived Info																									⊙		⊙	⊙	
Store Info					•	•	•	•	•	•	•	•	•	•			•	•	•	•	•	•	•	•		⊙			
Purge Info																											⊙	•	
Access Info																											•	⊙	
Best	1.00	1500	1.00	0.95	1.00	1.00	1.00	1.00	0.95	0.95	0.95	0.95	0.95	0.95	0.90	0.95	0.95	1.00	1.00	0.95	0.95	0.95	1.00	0.95	0.95	0.95	0.95	0.95	TBD
Worst	0.95	1350	0.95	0.90	0.90	0.90	1.00	1.00	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.95	0.90	0.90	0.90	1.00	0.90	0.90	0.90	0.90	0.90	TBD

Relationship

Figure E-3. QFD Representation of System Functions and Subfunctions and Evaluation Measures. This QFD depicts the interactions between the evaluation measure elements. The QFD also shows the relationship strength between the evaluation measures, and system functions and subfuntions.

APPENDIX F. ALTERNATIVES GENERATION

Through research, brainstorming and brain-writing, a list of possible alternatives were considered. The alternatives were generated by focusing on the functional model and the QFD results, keeping in mind the requirements listed in each of these analysis. The initial set of alternatives was generated from a table of options. Options to meet the requirements were categorized into COMMS, a host system, host to communications interface, software services, PLI, display, identify, user interfaces, storage and deployability. The initial list of options is shown in Table F-1. From this set of options, alternatives were generated that make use of each of these options. The initial list of alternatives is shown in Table F-2.

Table F-1. Initial List of Options

COMMS	Host System	HOST to COMMS Interface	PLI	Display	Identify	User Interfaces	Storage	Deployability
INMARSAT(L-Band)	PDA	Tactical Internal Router	DGPS - Internal	Color	NIC (Network Interface Card)	keyboard	Internal	Man
KU Band SATCOM		Tactical External Router				touch screen		
UHF SATCOM	Laptop	Commercial Internal Router		Multiple Displays		trackball		
HF-LOS		Commercial External Router	DGPS - External		IP Based	mouse	External	Ship
UHF-LOS	Desktop					voice recognitions		
VHF-LOS		Tactical Internal Modem	GPS - External	Size		mic / speakers		
Wireless (802.11/802.16)	PC Based	Tactical External Modem			Other Hardware	headset	Remote	Helo
						camera		
TSAT	Rack mounted SBCs	Commercial Internal Modem	GPS - Internal	Readable in bright light		bio recognition	Removable	
New Technology	Mobile Terminal Equipment	Commercial External Modem				card reader		
Software Definable Radios								
Evaluation Criteria								
Bandwidth	Scalable	Properly interfaces between Host & COMMS	Accuracy = +/- 10 meters	(HSI)	Accuracy = 100%	(HSI)	24-48 hours of information	(HSI)
Range >= 30 Nm	Plug & Play						Probability =90-95%	
	Portable						Access <10s	
	Expandable						Sort <10s	
	Supportable						Search < 10s	
	Maintainable							
	Reliable							

Table F-1. This table represents the initial set of alternatives that were considered. The list was the result of research, brainstorming and brain writing techniques.

Table F-2. Preliminary List of xCMA System Alternatives

System Options									
System Name	**COMMS**	**Host System**	**Host to COMMS Interface**	**PLI**	**Display**	**Identify**	**User Interfaces**	**Storage**	**Deployability**
1	INMARSAT (L-Band)	Personal Digital Assistant (PDA)	Tactical Internal Router	DGPS Internal	Color	NIC Card	Keyboard, mouse, and smart card reader	Internal	Man
2	INMARSAT (L-Band)	Laptop	Tactical External Router	DGPS External	Monochrome	IP Based	Touchscreen, headset, and camera	External	New Technology
3	INMARSAT (L-Band)	Desktop	Commercial Internal Router	GPS Extrnal	LCD	Other Hardware	Keyboard, trackball, and bio-recognition	Remote	Helo
4	INMARSAT (L-Band)	PC Based	Commercial External Router	GPS Internal	PLASMA	New Technology	Voice recognition, mic and speakers	Removable	Man/ship
5	INMARSAT (L-Band)	Rack Mounted SBCs	Tactical Internal Modem	New Technology	CRT	IP Based	Voice recognition, and headset	None	Man/Helo
6	INMARSAT (L-Band)	Mobile Terminal Equipment	Tactical External Modem	GPS Extrnal	Multiple Displays	Other Hardware	Keyboard, mouse, and bio-recognition	Internal	Ship
7	INMARSAT (L-Band)	None	Commercial Internal Modem	DGPS External	None	None	Touchscreen, headset, and bio-recognition	Removable	Helo
8	INMARSAT (L-Band)	New Technology	Commercial External Modem	None	New Technology	NIC Card	Keyboard, trackball, and smart cad reader	New Technology	None

System Options									
System Name	**COMMS**	**Host System**	**Host to COMMS Interface**	**PLI**	**Display**	**Identify**	**User Interfaces**	**Storage**	**Deployability**
9	KU Band SATCOM	PDA	Tactical Internal Router	DGPS Internal	Color	NIC Card	Keyboard, mouse, and smart card reader	Internal	Man
10	KU Band SATCOM	Laptop	Tactical External Router	DGPS External	Monochrome	IP Based	Touchscreen, headset, and camera	External	New Technology
11	KU Band SATCOM	Desktop	Commercial Internal Router	GPS Extrnal	LCD	Other Hardware	Keyboard, trackball, and bio-recognition	Remote	Helo
12	KU Band SATCOM	PC Based	Commercial External Router	GPS Internal	PLASMA	New Technology	Voice recognition, mic and speakers	Removable	Man/ship
13	KU Band SATCOM	Rack Mounted SBCs	Tactical Internal Modem	New Technology	CRT	IP Based	Voice recognition, and headset	None	Man/Helo
14	KU Band SATCOM	Mobile Terminal Equipment	Tactical External Modem	GPS Extrnal	Multiple Displays	Other Hardware	Keyboard, mouse, and bio-recognition	Internal	Ship
15	KU Band SATCOM	None	Commercial Internal Modem	DGPS External	None	None	Touchscreen, headset, and bio-recognition	Removable	Helo
16	KU Band SATCOM	New Technology	Commercial External Modem	None	New Technology	NIC Card	Keyboard, trackball, and smart cad reader	New Technology	None

System Options									
System Name	**COMMS**	**Host System**	**Host to COMMS Interface**	**PLI**	**Display**	**Identify**	**User Interfaces**	**Storage**	**Deployability**
17	UHF SATCOM	PDA	Tactical Internal Router	DGPS Internal	Color	NIC Card	Keyboard, mouse, and smart card reader	Internal	Man
18	UHF SATCOM	Laptop	Tactical External Router	DGPS External	Monochrome	IP Based	Touchscreen, headset, and camera	External	New Technology
19	UHF SATCOM	Desktop	Commercial Internal Router	GPS Extrnal	LCD	Other Hardware	Keyboard, trackball, and bio-recognition	Remote	Helo
20	UHF SATCOM	PC Based	Commercial External Router	GPS Internal	PLASMA	New Technology	Voice recognition, mic and speakers	Removable	Man/ship
21	UHF SATCOM	Rack Mounted SBCs	Tactical Internal Modem	New Technology	CRT	IP Based	Voice recognition, and headset	None	Man/Helo
22	UHF SATCOM	Mobile Terminal Equipment	Tactical External Modem	GPS Extrnal	Multiple Displays	Other Hardware	Keyboard, mouse, and bio-recognition	Internal	Ship
23	UHF SATCOM	None	Commercial Internal Modem	DGPS External	None	None	Touchscreen, headset, and bio-recognition	Removable	Helo
24	UHF SATCOM	New Technology	Commercial External Modem	None	New Technology	NIC Card	Keyboard, trackball, and smart cad reader	New Technology	None

System Options									
System Name	**COMMS**	**Host System**	**Host to COMMS Interface**	**PLI**	**Display**	**Identify**	**User Interfaces**	**Storage**	**Deployability**
25	HF-LOS	PDA	Tactical Internal Router	DGPS Internal	Color	NIC Card	Keyboard, mouse, and smart card reader	Internal	Man
26	HF-LOS	Laptop	Tactical External Router	DGPS External	Monochrome	IP Based	Touchscreen, headset, and camera	External	New Technology
27	HF-LOS	Desktop	Commercial Internal Router	GPS Extrnal	LCD	Other Hardware	Keyboard, trackball, and bio-recognition	Remote	Helo
28	HF-LOS	PC Based	Commercial External Router	GPS Internal	PLASMA	New Technology	Voice recognition, mic and speakers	Removable	Man/ship
29	HF-LOS	Rack Mounted SBCs	Tactical Internal Modem	New Technology	CRT	IP Based	Voice recognition, and headset	None	Man/Helo
30	HF-LOS	Mobile Terminal Equipment	Tactical External Modem	GPS Extrnal	Multiple Displays	Other Hardware	Keyboard, mouse, and bio-recognition	Internal	Ship
31	HF-LOS	None	Commercial Internal Modem	DGPS External	None	None	Touchscreen, headset, and bio-recognition	Removable	Helo
32	HF-LOS	New Technology	Commercial External Modem	None	New Technology	NIC Card	Keyboard, trackball, and smart cad reader	New Technology	None

System Options									
System Name	**COMMS**	**Host System**	**Host to COMMS Interface**	**PLI**	**Display**	**Identify**	**User Interfaces**	**Storage**	**Deployability**
33	UHF-LOS	PDA	Tactical Internal Router	DGPS Internal	Color	NIC Card	Keyboard, mouse, and smart card reader	Internal	Man
34	UHF-LOS	Laptop	Tactical External Router	DGPS External	Monochrome	IP Based	Touchscreen, headset, and camera	External	New Technology
35	UHF-LOS	Desktop	Commercial Internal Router	GPS Extrnal	LCD	Other Hardware	Keyboard, trackball, and bio-recognition	Remote	Helo
36	UHF-LOS	PC Based	Commercial External Router	GPS Internal	PLASMA	New Technology	Voice recognition, mic and speakers	Removable	Man/ship
37	UHF-LOS	Rack Mounted SBCs	Tactical Internal Modem	New Technology	CRT	IP Based	Voice recognition, and headset	None	Man/Helo
38	UHF-LOS	Mobile Terminal Equipment	Tactical External Modem	GPS Extrnal	Multiple Displays	Other Hardware	Keyboard, mouse, and bio-recognition	Internal	Ship
39	UHF-LOS	None	Commercial Internal Modem	DGPS External	None	None	Touchscreen, headset, and bio-recognition	Removable	Helo
40	UHF-LOS	New Technology	Commercial External Modem	None	New Technology	NIC Card	Keyboard, trackball, and smart cad reader	New Technology	None

System Options									
System Name	**COMMS**	**Host System**	**Host to COMMS Interface**	**PLI**	**Display**	**Identify**	**User Interfaces**	**Storage**	**Deployability**
41	VHF-LOS	PDA	Tactical Internal Router	DGPS Internal	Color	NIC Card	Keyboard, mouse, and smart card reader	Internal	Man
42	VHF-LOS	Laptop	Tactical External Router	DGPS External	Monochrome	IP Based	Touchscreen, headset, and camera	External	New Technology
43	VHF-LOS	Desktop	Commercial Internal Router	GPS External	LCD	Other Hardware	Keyboard, trackball, and bio-recognition	Remote	Helo
44	VHF-LOS	PC Based	Commercial External Router	GPS Internal	PLASMA	New Technology	Voice recognition, mic and speakers	Removable	Man/ship
45	VHF-LOS	Rack Mounted SBCs	Tactical Internal Modem	New Technology	CRT	IP Based	Voice recognition, and headset	None	Man/Helo
46	VHF-LOS	Mobile Terminal Equipment	Tactical External Modem	GPS External	Multiple Displays	Other Hardware	Keyboard, mouse, and bio-recognition	Internal	Ship
47	VHF-LOS	None	Commercial Internal Modem	DGPS External	None	None	Touchscreen, headset, and bio-recognition	Removable	Helo
48	VHF-LOS	New Technology	Commercial External Modem	None	New Technology	NIC Card	Keyboard, trackball, and smart cad reader	New Technology	None

System Options									
System Name	**COMMS**	**Host System**	**Host to COMMS Interface**	**PLI**	**Display**	**Identify**	**User Interfaces**	**Storage**	**Deployability**
49	Wireless (802.11/802.16)	PDA	Tactical Internal Router	DGPS Internal	Color	NIC Card	Keyboard, mouse, and smart card reader	Internal	Man
50	Wireless (802.11/802.16)	Laptop	Tactical External Router	DGPS External	Monochrome	IP Based	Touchscreen, headset, and camera	External	New Technology
51	Wireless (802.11/802.16)	Desktop	Commercial Internal Router	GPS External	LCD	Other Hardware	Keyboard, trackball, and bio-recognition	Remote	Helo
52	Wireless (802.11/802.16)	PC Based	Commercial External Router	GPS Internal	PLASMA	New Technology	Voice recognition, mic and speakers	Removable	Man/ship
53	Wireless (802.11/802.16)	Rack Mounted SBCs	Tactical Internal Modem	New Technology	CRT	IP Based	Voice recognition, and headset	None	Man/Helo
54	Wireless (802.11/802.16)	Mobile Terminal Equipment	Tactical External Modem	GPS External	Multiple Displays	Other Hardware	Keyboard, mouse, and bio-recognition	Internal	Ship
55	Wireless (802.11/802.16)	None	Commercial Internal Modem	DGPS External	None	None	Touchscreen, headset, and bio-recognition	Removable	Helo
56	Wireless (802.11/802.16)	New Technology	Commercial External Modem	None	New Technology	NIC Card	Keyboard, trackball, and smart cad reader	New Technology	None

System Options									
System Name	**COMMS**	**Host System**	**Host to COMMS Interface**	**PLI**	**Display**	**Identify**	**User Interfaces**	**Storage**	**Deployability**
57	Transformational SATCOM	PDA	Tactical Internal Router	DGPS Internal	Color	NIC Card	Keyboard, mouse, and smart card reader	Internal	Man
58	Transformational SATCOM	Laptop	Tactical External Router	DGPS External	Monochrome	IP Based	Touchscreen, headset, and camera	External	New Technology
59	Transformational SATCOM	Desktop	Commercial Internal Router	GPS External	LCD	Other Hardware	Keyboard, trackball, and bio-recognition	Remote	Helo
60	Transformational SATCOM	PC Based	Commercial External Router	GPS Internal	PLASMA	New Technology	Voice recognition, mic and speakers	Removable	Man/ship
61	Transformational SATCOM	Rack Mounted SBCs	Tactical Internal Modem	New Technology	CRT	IP Based	Voice recognition, and headset	None	Man/Helo
62	Transformational SATCOM	Mobile Terminal Equipment	Tactical External Modem	GPS External	Multiple Displays	Other Hardware	Keyboard, mouse, and bio-recognition	Internal	Ship
63	Transformational SATCOM	None	Commercial Internal Modem	DGPS External	None	None	Touchscreen, headset, and bio-recognition	Removable	Helo
64	Transformational SATCOM	New Technology	Commercial External Modem	None	New Technology	NIC Card	Keyboard, trackball, and smart cad reader	New Technology	None

System Options									
System Name	**COMMS**	**Host System**	**Host to COMMS Interface**	**PLI**	**Display**	**Identify**	**User Interfaces**	**Storage**	**Deployability**
65	Software Definable Radios	PDA	Tactical Internal Router	DGPS Internal	Color	NIC Card	Keyboard, mouse, and smart card reader	Internal	Man
66	Software Definable Radios	Laptop	Tactical External Router	DGPS External	Monochrome	IP Based	Touchscreen, headset, and camera	External	New Technology
67	Software Definable Radios	Desktop	Commercial Internal Router	GPS External	LCD	Other Hardware	Keyboard, trackball, and bio-recognition	Remote	Helo
68	Software Definable Radios	PC Based	Commercial External Router	GPS Internal	PLASMA	New Technology	Voice recognition, mic and speakers	Removable	Man/ship
69	Software Definable Radios	Rack Mounted SBCs	Tactical Internal Modem	New Technology	CRT	IP Based	Voice recognition, and headset	None	Man/Helo
70	Software Definable Radios	Mobile Terminal Equipment	Tactical External Modem	GPS External	Multiple Displays	Other Hardware	Keyboard, mouse, and bio-recognition	Internal	Ship
71	Software Definable Radios	None	Commercial Internal Modem	DGPS External	None	None	Touchscreen, headset, and bio-recognition	Removable	Helo
72	Software Definable Radios	New Technology	Commercial External Modem	None	New Technology	NIC Card	Keyboard, trackball, and smart cad reader	New Technology	None

Table F-2. This table represents the alternatives that were generated as a result of the initial set of options as shown in Table F-1.

Assumptions used to generate the initial list of alternatives are:

- Commercial Satellite Communications will use Commercial router/modem
- Military Satellite Communications will use Tactical router/modem;
- Wireless will use a commercial router/modem
- TSAT is a transformational satellite
- Web based network Protocols are implemented

Further research showed that IEEE 802.11 as well as all the LOS options do not meet the 30 nautical mile range requirement and are deleted from the alternatives [Javvin Network Management and Security, 2007].

Research further showed that INMARSAT does not handle the streaming video requirements. New technology will be discussed for future options, but will not be evaluated due to the lack of system specifications available for evaluation. Upon defining MTE it is determined that MTE is another form of a SBC. These two categories are combined.

Keeping the above assumptions in mind and considering the restrictions found through research for other protocols and tactical equipment, an updated list of options was generated. The updated list of options is shown in Table F-3. From this list an updated list of alternatives was generated and is shown in Table F-4.

Table F-3. Updated List of xCMA System Options

<table>
<tr><th>COMMS</th><th>Host System</th><th>Router/Modem</th><th>Software & Services</th><th>PLI</th><th>Display</th><th>Identify</th></tr>
<tr><td>SATCOM- Commercial</td><td rowspan="3">Laptop</td><td rowspan="4">Commercial</td><td rowspan="2">DII COE</td><td rowspan="8">GPS</td><td rowspan="4">LCD</td><td rowspan="4">MAC / IP Address</td></tr>
<tr><td rowspan="2">Wireless (802.16 or equiv)</td></tr>
<tr><td rowspan="2">Specific Application S/W</td></tr>
<tr><td rowspan="2">SATCOM - Military/Government</td><td rowspan="2">New Technology</td></tr>
<tr><td rowspan="4">Tactical</td><td rowspan="2">CMA Toolset</td><td rowspan="4">New Technology</td><td rowspan="4">Other Hardware / New Technology</td></tr>
<tr><td rowspan="3">Software Definable Radios</td><td rowspan="3">SBC</td></tr>
<tr><td></td></tr>
<tr><td>Web based Common Operational Picture</td></tr>
<tr><td colspan="7">Evaluation Criteria</td></tr>
<tr><td>Bandwidth</td><td>Scalable</td><td>Properly interfaces between Host & COMMS</td><td>N/A</td><td>Accuracy = +/- 10 meters</td><td>(HSI)</td><td>Accuracy = 100%</td></tr>
<tr><td>Range >= 30 Nm</td><td>Plug & Play</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td>Portable</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td>Expandable</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td>Supportable</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td>Maintainable</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td>Reliable</td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Table F-3. This table represents the revised list of options that were generated as a result of the documented assumptions and restrictions identified in research.

Table F-4. Updated List of Alternatives

COMMS	Host System	Router/Modem	PLI	Display	Identify
SATCOM – Commercial	Laptop	Commercial	GPS	LCD	MAC/IP
SATCOM – Commercial	New Technology	Commercial	GPS	New Technology	Other HW, new tech
SATCOM – Commercial	SBC	Commercial	GPS	LCD	MAC/IP
SATCOM – Commercial	Mobile Terminal Equipment	Commercial	GPS	LCD	Other HW, New Tech
SATCOM - Military/Government	Laptop	Tactical	GPS	LCD	MAC/IP
SATCOM - Military/Government	New Technology	Tactical	GPS	New Technology	Other HW, new tech
SATCOM - Military/Government	SBC	Tactical	GPS	LCD	MAC/IP
SATCOM - Military/Government	Mobile Terminal Equipment	Tactical	GPS	LCD	Other HW, New Tech
Wireless 802.16	Laptop	Commercial	GPS	LCD	MAC/IP
Wireless 802.16	New Technology	Commercial	GPS	New Technology	Other HW, new tech
Wireless 802.16	SBC	Commercial	GPS	LCD	MAC/IP
Wireless 802.16	Mobile Terminal Equipment	Commercial	GPS	LCD	Other HW, New Tech
Software Defined Radio	Laptop	Commercial	GPS	LCD	MAC/IP
Software Defined Radio	New Technology	Commercial	GPS	New Technology	Other HW, new tech
Software Defined Radio	SBC	Commercial	GPS	LCD	MAC/IP
Software Defined Radio	Mobile Terminal Equipment	Commercial	GPS	LCD	Other HW, New Tech

This table represents the revised list of alternatives that were generated as a result of the revised options as shown in Table F-3.

With the intent to provide foreign allies and merchant vessels the xCMA system, and understanding that restrictions exist in the use of tactical equipment, all tactical equipment was eliminated from the list of alternatives. SDRs are network agnostic, thus the implementation and use of SDRs require an communications system, i.e. 802.16m wireless or SATCOM. Given this restriction, SDRs were eliminated from the list of alternatives.

Zwicky's Morphological Box

The development of alternatives identified four primary alternatives and a non materiel solution. These options are used to determine the system designs by selecting different tracks. They are listed below and graphically in Table G-5 known as Zwicky's Morphological Box.

- Non Materiel – Change CONOPS; use the existing networks and infrastructure. Modify mission responsibilities and operational concepts.
- Develop a SATCOM-Laptop system using existing commercial SATCOM with a COTS laptop.
- Develop a SATCOM-SBC system using existing commercial SATCOM with a SBC MTE.
- Develop a Wireless-Laptop system using 802.16m wireless protocols with a COTS laptop.
- Develop a Wireless -SBC system using 802.16m wireless protocols with a SBC MTE.

Table F-5. Zwicky's Mophological Box of possible xCMA system alternatives.

Design Name	System Functions: COMMS	Host System	Router/Modem	PLI	Display	Identify
SATCOM-Laptop SATCOM-SBC	ATCOM- Commerc	Laptop	COTS	GPS	LCD	IC MAC Address
Wireless-Laptop Wireless-SBC	Wireless 802.16	SBC MTE				
Non Materiel						

Table F-5 identifies four primary alternatives and a non materiel solution. These options were used to determine the system designs. This representation of system alternatives is a systems engineering tool known as Zwicky's Morphological Box.

This colorfully illustrates the creation of each xCMA system candidate. Different system attributes are selected from left to right under the System Functions title box. Mixing and matching the different attributes generates combinations of options for each alternative.

The non-materiel solution uses the existing networks and infrastructure. Modification of mission responsibilities, operational concepts and technologies would not provide adequate CMA connectivity to the disconnected vessel or user. Limited connectivity could be provided on an adhoc basis using existing UHF/VHF radio telephones and possibly messenger services (small boat and helicopter delivery of maps, orders). This does not provide the capability for Node 5 to effectively and efficiently communicate with the humanitarian operation vessels using streaming video, text, pictures, e-mail, and chat. Since this solution does not meet the requirement it is eliminated from the list of alternatives. The final list of alternatives is shown in Table F-6.

Table F-6. Final List of xCMA system alternatives

Alternatives	COMMS	Host System	Router/Modem	PLI	Display	Identify
1. SATCOM-Laptop	SATCOM - Commercial	Laptop	Commercial	GPS	LCD	MAC/IP
2. SATCOM-SBC	SATCOM - Commercial	Integrated SBC (MTE)	Commercial	GPS	LCD	MAC/IP
3. Wireless-Laptop	Wireless 802.16	Laptop	Commercial	GPS	LCD	MAC/IP
4. Wireless-SBC	Wireless 802.16	Integrated SBC (MTE)	Commercial	GPS	LCD	MAC/IP

Table F-6 provides the final list of alternatives generated.

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APPENDIX G. RELIABILITY MODELING

The QFD results show reliability to be of major concern in the selection of the xCMA system. Since reliability has a very high rating factor, modeling and simulation is applied to determine the reliability of each of the four proposed alternatives.

A mathematical model was constructed using Microsoft Excel. To properly calculate a 95% confidence interval and reduce errors in the simulation process, the model is constructed using 300 replications.

Table G-1 detailed the source of MTBF values used in the simulation. As part of the reliability simulation actual values for MTBF are used on existing systems. A simulation summary is given for each of the alternatives in Tables G-2 through G-5. Table G-2 shows the detailed summary for Alternative 1 -- SATCOM-Laptop. Table G-3 shows the detailed summary for Alternative 2 -- SATCOM-SBC. Table G-4 shows the detailed summary for Alternative 3 -- Wireless-Laptop. Table G-5 shows the detailed summary for Alternative 4 -- Wireless-SBC. The xCMA system reliability for each alternative is shown in Table G-6.

Table G-1. Manufacturers' published MTBF values and Calculated Reliabilities

Option	Component	MTBF									Avgerage MTBF	-1/MTBF	Reliability for ~14 days
	Communications: SATCOM-Commercial	2,200	16,206	8,760							9,055	(0.000110432)	0.96
	Host System: Laptop	10,000									10,000	(0.000100000)	0.97
1	**Router/Modem:** Commercial	1,556,100	1,123,223	586,683	706,709	300,000	342,000	316,000	350,000		660,089	(0.000001515)	1.00
	Display: LCD	20,000	25,000								22,500	(0.000044444)	0.99
	Identify: MAC/IP	139,416									139,416	(0.000007173)	1.00
	Communications: SATCOM-Commercial	2,200	16,206	8,760							9,055	(0.000110432)	0.96
	Host System: Single Board Computer (MTE)	144,036									144,036	(0.000006943)	1.00
2	**Router/Modem:** Commercial	1,556,100	1,123,223	586,683	706,709	300,000	342,000	316,000	350,000		660,089	(0.000001515)	1.00
	Display: LCD	20,000	25,000								22,500	(0.000044444)	0.98
	Identify: MAC/IP	139,416									139,416	(0.000007173)	1.00
	Communications: Wireless 802.16	183,000	100,000								141,500	(0.000007067)	1.00
	Host System: Laptop	10,000									10,000	(0.000100000)	0.97
3	**Router/Modem:** Commercial	1,556,100	1,123,223	586,683	706,709	300,000	342,000	316,000	350,000		660,089	(0.000001515)	1.00
	Display: LCD	20,000	25,000								22,500	(0.000044444)	0.99
	Identify: MAC/IP	139,416									139,416	(0.000007173)	1.00
	Communications: Wireless 802.16	183,000	100,000								141,500	(0.000007067)	1.00
	Host System: Single Board Computer (MTE)	144,036									144,036	(0.000006943)	1.00
4	**Router/Modem:** Commercial	1,556,100	1,123,223	586,683	706,709	300,000	342,000	316,000	350,000		660,089	(0.000001515)	1.00
	Display: LCD	20,000	25,000								22,500	(0.000044444)	0.99
	Identify: MAC/IP	139,416									139,416	(0.000007173)	1.00

Table G-1 provides a summary of manufacturers' published MTBF values obtained from research of similar systems. The MTBF values for each component are averaged and used to calculate the component reliability.

Table G-2. Reliability Simulation for xCMA System Alternative 1: SATCOM-Laptop

Summary

		Components					
		Communications: SATCOM-Commercial	Host System: Laptop	Router/Modem: Commercial	Display: LCD	Identify: MAC/IP	System
1 Replication	Avgerage MTBF	9,055	10,000	660,089	22,500	139,416	
	-1/MTBF	-0.000110	-0.000100	-0.000002	-0.000044	-0.000007	
	Reliability for ~14 days	96.35%	96.69%	99.95%	98.55%	99.76%	91.55%
	System / Component Survive?	Yes	Yes	Yes	Yes	Yes	Yes
300 Replications	Num of Replications	300	300	300	300	300	
	Average Reliability	96.36%	96.69%	99.95%	98.52%	99.76%	91.52%
	SD of Reliability	0.04%	0.04%	0.00%	0.02%	0.00%	
	Conf Level	95%	95%	95%	95%	95%	
	Alpha	5%	5%	5%	5%	5%	
	Conf Width of Reliability	0.0048%	0.0041%	0.0001%	0.0021%	0.0003%	
	CI Low of Average Reliability	96.35%	96.69%	99.95%	98.52%	99.76%	
	CI High of Average Reliability	96.36%	96.70%	99.95%	98.52%	99.76%	
	System / Component Survive?	Yes	Yes	Yes	Yes	Yes	Yes

Replications

	Components				
	Communications: SATCOM-Commercial	Host System: Laptop	Router/Modem: Commercial	Display: LCD	Identify: MAC/IP
1	96.35%	96.69%	99.95%	98.55%	99.76%
2	96.40%	96.67%	99.95%	98.48%	99.76%
3	96.36%	96.70%	99.95%	98.54%	99.76%
4	96.32%	96.71%	99.95%	98.51%	99.76%
5	96.40%	96.67%	99.95%	98.51%	99.76%
6	96.30%	96.65%	99.95%	98.53%	99.76%
7	96.38%	96.65%	99.95%	98.50%	99.76%
8	96.28%	96.68%	99.95%	98.49%	99.76%
9	96.34%	96.76%	99.95%	98.52%	99.76%
10	96.37%	96.73%	99.95%	98.55%	99.76%
11	96.35%	96.71%	99.95%	98.52%	99.76%
12	96.38%	96.69%	99.95%	98.50%	99.76%
13	96.34%	96.69%	99.95%	98.50%	99.76%
14	96.44%	96.71%	99.95%	98.53%	99.76%
15	96.32%	96.66%	99.95%	98.51%	99.76%
16	96.39%	96.73%	99.95%	98.49%	99.76%
17	96.39%	96.70%	99.95%	98.51%	99.76%
18	96.37%	96.72%	99.95%	98.51%	99.76%
19	96.32%	96.71%	99.95%	98.54%	99.76%
20	96.25%	96.74%	99.95%	98.52%	99.76%
21	96.37%	96.66%	99.95%	98.53%	99.76%
22	96.29%	96.72%	99.95%	98.50%	99.76%
23	96.42%	96.66%	99.95%	98.51%	99.76%
24	96.35%	96.67%	99.95%	98.51%	99.76%
25	96.37%	96.68%	99.95%	98.52%	99.77%
26	96.33%	96.69%	99.95%	98.54%	99.76%
27	96.25%	96.72%	99.95%	98.51%	99.75%
28	96.32%	96.66%	99.95%	98.52%	99.76%
29	96.35%	96.71%	99.95%	98.52%	99.76%
30	96.29%	96.80%	99.95%	98.49%	99.76%
31	96.38%	96.62%	99.95%	98.52%	99.76%
32	96.30%	96.67%	99.95%	98.52%	99.76%
33	96.31%	96.76%	99.95%	98.53%	99.75%
34	96.38%	96.76%	99.95%	98.50%	99.76%
35	96.29%	96.71%	99.95%	98.54%	99.76%
36	96.39%	96.76%	99.95%	98.55%	99.77%
37	96.41%	96.73%	99.95%	98.50%	99.76%
38	96.42%	96.68%	99.95%	98.50%	99.76%
39	96.32%	96.74%	99.95%	98.54%	99.76%
40	96.33%	96.69%	99.95%	98.53%	99.76%
296	96.38%	96.69%	99.95%	98.51%	99.76%
297	96.36%	96.64%	99.95%	98.53%	99.76%
298	96.38%	96.72%	99.95%	98.52%	99.76%
299	96.38%	96.69%	99.95%	98.50%	99.76%
300	96.44%	96.75%	99.95%	98.53%	99.76%

Table G-2 summarizes the reliability simulation results for SATCOM-Laptop combination.

Table G-3. Reliability Simulation for xCMA System Alternative 2: SATCOM-SBC

Summary

		Components					System
		Communications: SATCOM-Commercial	Host System: Single Board Computer (MTE)	Router/Modem: Commercial	Display: LCD	Identify: MAC/IP	
1 Replication	Avgerage MTBF	9,055	144,036	660,089	22,500	139,416	
	-1/MTBF	-0.000110	-0.000007	-0.000002	-0.000044	-0.000007	
	Reliability for ~14 days	96.33%	99.76%	99.95%	98.54%	99.76%	94.42%
	System / Component Survive?	Yes	Yes	Yes	Yes	Yes	Yes
300 Replications	Num of Replications	300	300	300	300	300	
	Average Reliability	96.36%	99.77%	99.95%	98.52%	99.76%	94.43%
	SD of Reliability	0.04%	0.00%	0.00%	0.02%	0.00%	
	Conf Level	95%	95%	95%	95%	95%	
	Alpha	5%	5%	5%	5%	5%	
	Conf Width of Reliability	0.0048%	0.0003%	0.0001%	0.0021%	0.0003%	
	CI Low of Average Reliability	96.35%	99.77%	99.95%	98.52%	99.76%	
	CI High of Average Reliability	96.36%	99.77%	99.95%	98.52%	99.76%	
	System / Component Survive?	Yes	Yes	Yes	Yes	Yes	Yes

Replications

	Components				
	Communications: SATCOM-Commercial	Host System: Laptop	Router/Modem: Commercial	Display: LCD	Identify: MAC/IP
1	96.33%	99.76%	99.95%	98.54%	99.76%
2	96.40%	99.77%	99.95%	98.52%	99.76%
3	96.31%	99.76%	99.95%	98.52%	99.75%
4	96.41%	99.77%	99.95%	98.53%	99.76%
5	96.38%	99.77%	99.95%	98.51%	99.76%
6	96.31%	99.77%	99.95%	98.51%	99.76%
7	96.32%	99.77%	99.95%	98.53%	99.76%
8	96.40%	99.77%	99.95%	98.55%	99.76%
9	96.34%	99.77%	99.95%	98.51%	99.76%
10	96.31%	99.77%	99.95%	98.52%	99.76%
11	96.38%	99.77%	99.95%	98.48%	99.76%
12	96.38%	99.76%	99.95%	98.50%	99.76%
13	96.33%	99.77%	99.95%	98.54%	99.76%
14	96.34%	99.76%	99.95%	98.52%	99.76%
15	96.35%	99.76%	99.95%	98.55%	99.76%
16	96.30%	99.77%	99.95%	98.52%	99.76%
17	96.30%	99.76%	99.95%	98.53%	99.76%
18	96.35%	99.76%	99.95%	98.52%	99.76%
19	96.34%	99.77%	99.95%	98.57%	99.76%
20	96.31%	99.77%	99.95%	98.49%	99.76%
21	96.31%	99.77%	99.95%	98.56%	99.76%
22	96.38%	99.77%	99.95%	98.50%	99.76%
23	96.32%	99.77%	99.95%	98.55%	99.76%
24	96.37%	99.77%	99.95%	98.50%	99.75%
25	96.39%	99.77%	99.95%	98.54%	99.76%
26	96.33%	99.77%	99.95%	98.49%	99.76%
27	96.41%	99.77%	99.95%	98.53%	99.76%
28	96.35%	99.77%	99.95%	98.51%	99.76%
29	96.38%	99.77%	99.95%	98.50%	99.76%
30	96.34%	99.77%	99.95%	98.54%	99.76%
31	96.46%	99.76%	99.95%	98.54%	99.76%
32	96.34%	99.76%	99.95%	98.52%	99.77%
33	96.30%	99.76%	99.95%	98.51%	99.76%
34	96.36%	99.77%	99.95%	98.51%	99.76%
35	96.39%	99.76%	99.95%	98.51%	99.76%
36	96.41%	99.77%	99.95%	98.50%	99.75%
37	96.33%	99.76%	99.95%	98.54%	99.76%
38	96.29%	99.77%	99.95%	98.53%	99.76%
39	96.40%	99.77%	99.95%	98.53%	99.76%
40	96.39%	99.76%	99.95%	98.54%	99.76%
296	96.43%	99.77%	99.95%	98.53%	99.76%
297	96.36%	99.77%	99.95%	98.53%	99.76%
298	96.46%	99.77%	99.95%	98.50%	99.76%
299	96.34%	99.77%	99.95%	98.55%	99.76%
300	96.35%	99.77%	99.95%	98.51%	99.76%

Table G-3 summarizes the reliability simulation results for the SATCOM-SBC combination.

Table G-4. Reliability Simulation for xCMA System Alternative 3: Wireless-Laptop

Summary

		Components					System
		Communications: Wireless 802.16	Host System: Laptop	Router/Modem: Commercial	Display: LCD	Identify: MAC/IP	System
1 Replication	Avgerage MTBF	141,500	10,000	660,089	22,500	139,416	
	-1/MTBF	-0.000007	-0.000100	-0.000002	-0.000044	-0.000007	
	Reliability for ~14 days	99.76%	96.70%	99.95%	98.52%	99.76%	94.77%
	System / Component Survive?	Yes	Yes	Yes	Yes	Yes	Yes
300 Replications	Num of Replications	300	300	300	300	300	
	Average Reliability	99.76%	96.69%	99.95%	98.52%	99.76%	94.75%
	SD of Reliability	0.00%	0.04%	0.00%	0.02%	0.00%	
	Conf Level	95%	95%	95%	95%	95%	
	Alpha	5%	5%	5%	5%	5%	
	Conf Width of Reliability	0.0003%	0.0045%	0.0001%	0.0019%	0.0003%	
	CI Low of Average Reliability	99.76%	96.69%	99.95%	98.51%	99.76%	
	CI High of Average Reliability	99.76%	96.70%	99.95%	98.52%	99.76%	
	System / Component Survive?	Yes	Yes	Yes	Yes	Yes	Yes

Replications

	Components				
	Communications: SATCOM-Commercial	Host System: Laptop	Router/Modem: Commercial	Display: LCD	Identify: MAC/IP
1	99.76%	96.70%	99.95%	98.52%	99.76%
2	99.76%	96.78%	99.95%	98.53%	99.76%
3	99.76%	96.65%	99.95%	98.55%	99.75%
4	99.77%	96.74%	99.95%	98.50%	99.76%
5	99.76%	96.71%	99.95%	98.51%	99.76%
6	99.77%	96.69%	99.95%	98.51%	99.76%
7	99.76%	96.71%	99.95%	98.50%	99.76%
8	99.76%	96.74%	99.95%	98.51%	99.76%
9	99.76%	96.68%	99.95%	98.53%	99.76%
10	99.76%	96.77%	99.95%	98.50%	99.76%
11	99.76%	96.61%	99.95%	98.52%	99.76%
12	99.77%	96.66%	99.95%	98.54%	99.75%
13	99.76%	96.70%	99.95%	98.50%	99.76%
14	99.76%	96.73%	99.95%	98.52%	99.76%
15	99.77%	96.69%	99.95%	98.54%	99.76%
16	99.76%	96.69%	99.95%	98.53%	99.76%
17	99.76%	96.65%	99.95%	98.51%	99.77%
18	99.76%	96.70%	99.95%	98.53%	99.76%
19	99.76%	96.67%	99.95%	98.53%	99.76%
20	99.76%	96.69%	99.95%	98.52%	99.76%
21	99.76%	96.69%	99.95%	98.53%	99.76%
22	99.76%	96.66%	99.95%	98.52%	99.76%
23	99.76%	96.72%	99.95%	98.51%	99.76%
24	99.77%	96.72%	99.95%	98.53%	99.76%
25	99.76%	96.69%	99.95%	98.49%	99.76%
26	99.76%	96.71%	99.95%	98.49%	99.76%
27	99.77%	96.70%	99.95%	98.53%	99.76%
28	99.76%	96.67%	99.95%	98.53%	99.76%
29	99.76%	96.70%	99.95%	98.54%	99.76%
30	99.77%	96.68%	99.95%	98.54%	99.76%
31	99.76%	96.64%	99.95%	98.53%	99.76%
32	99.76%	96.78%	99.95%	98.52%	99.75%
33	99.76%	96.74%	99.95%	98.52%	99.76%
34	99.77%	96.69%	99.95%	98.53%	99.76%
35	99.76%	96.73%	99.95%	98.51%	99.76%
36	99.76%	96.64%	99.95%	98.51%	99.76%
37	99.77%	96.71%	99.95%	98.53%	99.76%
38	99.76%	96.61%	99.95%	98.53%	99.76%
39	99.77%	96.62%	99.95%	98.53%	99.76%
40	99.77%	96.73%	99.95%	98.56%	99.76%
296	99.76%	96.68%	99.95%	98.50%	99.76%
297	99.77%	96.67%	99.95%	98.48%	99.76%
298	99.76%	96.76%	99.95%	98.52%	99.76%
299	99.76%	96.72%	99.95%	98.50%	99.76%
300	99.76%	96.66%	99.95%	98.52%	99.76%

Table G-4 summarizes the reliability simulation results for the Wireless-Laptop combination.

Table G-5. Reliability Simulation for xCMA System Alternative 4: Wireless-SBC

Summary

		Components					System
		Communications: Wireless 802.16	Host System: Single Board Computer (MTE)	Router/Modem: Commercial	Display: LCD	Identify: MAC/IP	System
1 Replication	Avgerage MTBF	141,500	144,036	660,089	22,500	139,416	
	-1/MTBF	-0.000007	-0.000007	-0.000002	-0.000044	-0.000007	
	Reliability for ~14 days	99.77%	99.77%	99.95%	98.50%	99.76%	97.76%
	System / Component Survive?	Yes	Yes	Yes	Yes	Yes	Yes
300 Replications	Num of Replications	300	300	300	300	300	
	Average Reliability	99.76%	99.77%	99.95%	98.52%	99.76%	97.77%
	SD of Reliability	0.00%	0.00%	0.00%	0.02%	0.00%	
	Conf Level	95%	95%	95%	95%	95%	
	Alpha	5%	5%	5%	5%	5%	
	Conf Width of Reliability	0.0003%	0.0003%	0.0001%	0.0020%	0.0003%	
	CI Low of Average Reliability	99.76%	99.77%	99.95%	98.52%	99.76%	
	CI High of Average Reliability	99.76%	99.77%	99.95%	98.52%	99.76%	
	System / Component Survive?	Yes	Yes	Yes	Yes	Yes	Yes

Replications

	Components				
	Communications: SATCOM-Commercial	Host System: Laptop	Router/Modem: Commercial	Display: LCD	Identify: MAC/IP
1	99.77%	99.77%	99.95%	98.50%	99.76%
2	99.76%	99.77%	99.95%	98.54%	99.76%
3	99.77%	99.76%	99.95%	98.49%	99.76%
4	99.77%	99.76%	99.95%	98.51%	99.76%
5	99.76%	99.77%	99.95%	98.54%	99.76%
6	99.76%	99.77%	99.95%	98.51%	99.76%
7	99.76%	99.77%	99.95%	98.56%	99.76%
8	99.76%	99.77%	99.95%	98.50%	99.76%
9	99.76%	99.77%	99.95%	98.51%	99.76%
10	99.76%	99.76%	99.95%	98.54%	99.76%
11	99.77%	99.77%	99.95%	98.50%	99.76%
12	99.76%	99.76%	99.95%	98.51%	99.76%
13	99.77%	99.77%	99.95%	98.52%	99.76%
14	99.76%	99.77%	99.95%	98.50%	99.76%
15	99.77%	99.77%	99.95%	98.55%	99.76%
16	99.77%	99.77%	99.95%	98.49%	99.76%
17	99.76%	99.77%	99.95%	98.53%	99.76%
18	99.76%	99.76%	99.95%	98.51%	99.76%
19	99.76%	99.77%	99.95%	98.50%	99.76%
20	99.76%	99.76%	99.95%	98.53%	99.76%
21	99.76%	99.76%	99.95%	98.52%	99.76%
22	99.77%	99.77%	99.95%	98.50%	99.75%
23	99.76%	99.76%	99.95%	98.50%	99.76%
24	99.76%	99.76%	99.95%	98.51%	99.76%
25	99.76%	99.77%	99.95%	98.50%	99.76%
26	99.76%	99.76%	99.95%	98.49%	99.75%
27	99.76%	99.77%	99.95%	98.54%	99.76%
28	99.76%	99.77%	99.95%	98.49%	99.76%
29	99.76%	99.77%	99.95%	98.53%	99.76%
30	99.77%	99.77%	99.95%	98.48%	99.75%
31	99.76%	99.77%	99.95%	98.51%	99.76%
32	99.76%	99.76%	99.95%	98.52%	99.76%
33	99.76%	99.77%	99.95%	98.53%	99.76%
34	99.77%	99.77%	99.95%	98.53%	99.76%
35	99.77%	99.77%	99.95%	98.53%	99.76%
36	99.76%	99.76%	99.95%	98.51%	99.76%
37	99.76%	99.77%	99.95%	98.52%	99.75%
38	99.76%	99.77%	99.95%	98.53%	99.76%
39	99.76%	99.77%	99.95%	98.49%	99.76%
40	99.76%	99.77%	99.95%	98.51%	99.76%
296	99.76%	99.77%	99.95%	98.52%	99.76%
297	99.76%	99.77%	99.95%	98.52%	99.76%
298	99.76%	99.77%	99.95%	98.53%	99.76%
299	99.77%	99.76%	99.95%	98.51%	99.77%
300	99.76%	99.77%	99.95%	98.51%	99.76%

Table G-5 summarizes the reliability simulation results for Wireless-SBC combination.

Table G-6. xCMA System Reliability Simulation Results

Option	Component	Avgerage MTBF	-1/MTBF	Reliability for ~14 days	Num of Replications	Average Reliability	SD of Reliability	Conf Level	Alpha	Conf Width of Reliability	CI Low of Average Reliability	CI High of Average Reliability	Component Survive?	System Reliability	System MTBF (hrs)
1	**Communications:** SATCOM-Commercial	9,055	(0.000110432)	0.96	300	96.36%	0.0422%	95%	5%	0.0048%	96.35%	96.36%	Yes	91.52%	3,794
	Host System: Laptop	10,000	(0.000100000)	0.97	300	96.69%	0.0364%	95%	5%	0.0041%	96.69%	96.70%	Yes		
	Router/Modem: Commercial	660,089	(0.000001515)	1.00	300	99.95%	0.0006%	95%	5%	0.0001%	99.95%	99.95%	Yes		
	Display: LCD	22,500	(0.000044444)	0.99	300	98.52%	0.0182%	95%	5%	0.0021%	98.52%	98.52%	Yes		
	Identify: MAC/IP	139,416	(0.000007173)	1.00	300	99.76%	0.0027%	95%	5%	0.0003%	99.76%	99.76%	Yes		
2	**Communications:** SATCOM-Commercial	9,055	(0.000110432)	0.96	300	96.36%	0.0420%	95%	5%	0.0048%	96.35%	96.36%	Yes	94.43%	5,864
	Host System: Single Board Computer (MTE)	144,036	(0.000006943)	1.00	300	99.77%	0.0026%	95%	5%	0.0003%	99.77%	99.77%	Yes		
	Router/Modem: Commercial	660,089	(0.000001515)	1.00	300	99.95%	0.0006%	95%	5%	0.0001%	99.95%	99.95%	Yes		
	Display: LCD	22,500	(0.000044444)	0.99	300	98.52%	0.0182%	95%	5%	0.0021%	98.52%	98.52%	Yes		
	Identify: MAC/IP	139,416	(0.000007173)	1.00	300	99.76%	0.0029%	95%	5%	0.0003%	99.76%	99.76%	Yes		
3	**Communications:** Wireless 802.16	141,500	(0.000007067)	1.00	300	99.76%	0.0029%	95%	5%	0.0003%	99.76%	99.76%	Yes	94.75%	6,236
	Host System: Laptop	10,000	(0.000100000)	0.97	300	96.69%	0.0397%	95%	5%	0.0045%	96.69%	96.70%	Yes		
	Router/Modem: Commercial	660,089	(0.000001515)	1.00	300	99.95%	0.0006%	95%	5%	0.0001%	99.95%	99.95%	Yes		
	Display: LCD	22,500	(0.000044444)	0.99	300	98.52%	0.0167%	95%	5%	0.0019%	98.51%	98.52%	Yes		
	Identify: MAC/IP	139,416	(0.000007173)	1.00	300	99.76%	0.0027%	95%	5%	0.0003%	99.76%	99.76%	Yes		
4	**Communications:** Wireless 802.16	141,500	(0.000007067)	1.00	300	99.76%	0.0029%	95%	5%	0.0003%	99.76%	99.76%	Yes	97.77%	14,893
	Host System: Single Board Computer (MTE)	144,036	(0.000006943)	1.00	300	99.77%	0.0029%	95%	5%	0.0003%	99.77%	99.77%	Yes		
	Router/Modem: Commercial	660,089	(0.000001515)	1.00	300	99.95%	0.0006%	95%	5%	0.0001%	99.95%	99.95%	Yes		
	Display: LCD	22,500	(0.000044444)	0.99	300	98.52%	0.0178%	95%	5%	0.0020%	98.52%	98.52%	Yes		
	Identify: MAC/IP	139,416	(0.000007173)	1.00	300	99.76%	0.0029%	95%	5%	0.0003%	99.76%	99.76%	Yes		

Table G-6 provides a summary of the xCMA system reliability simulation results. These results are based on 300 replications with 95% confidence level.

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APPENDIX H. THROUGHPUT MODELING

A mathematical model was constructed using Microsoft Excel. A summary of the mathematical model results for the SATCOM Laptop and SATCOM SBC options is shown in Figure H-1. A summary of the mathematical model results for the Wireless Laptop and Wireless SBC options is shown Figure H-2. To properly calculate a 95% confidence interval and reduce errors in the simulation process, the model is constructed using 30 replications for each of the listed alternatives, which are then repeated in a set of 500 totaling 15,000 replications. The simulation results for the SATCOM Laptop and SATCOM SBC are listed in Table H-1. Simulation results for the Wireless alternatives are listed in Table H-2. Immediately following the summary are detailed results for the 500 replications.

M/M/s

Arrival rate (Kbps)	128
Service rate (Kbps)	235
Number of servers	1

Assumes Poisson process for arrivals and services.

Utilization	**54.47%**
P(0), probability that the system is empty	**0.4553**
Lq, expected queue length	**0.6516**
L, expected number in system	**1.1963**
Wq, expected time in queue	**0.00509**
W, expected total time in system (sec)	**0.00935**
Probability that data waits to be processed	**1.36%**

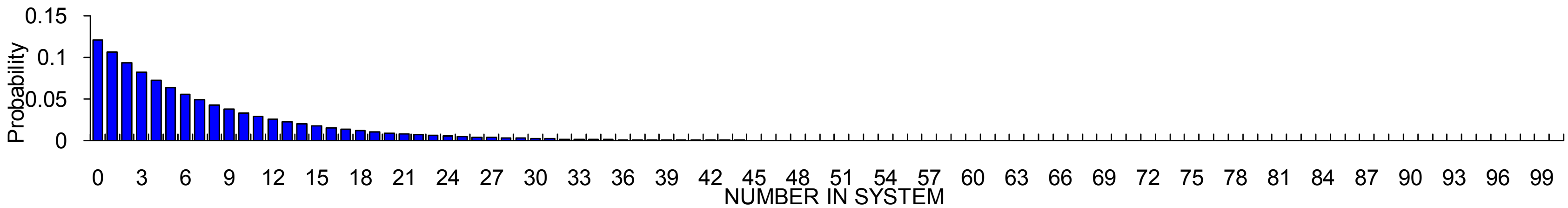

Figure H-1. Mathematical model results for SATCOM-Laptop and SATCOM-SBC systems. This figure captures the results from the mathematical model for SATCOM- Laptop and SATCOM-SBC systems.

M/M/s

Arrival rate (Kbps)	**128**	Assumes Poisson process for arrivals and services.
Service rate (Kbps)	**3,729**	
Number of servers	**1**	

Utilization	**3.43%**
P(0), probability that the system is empty	**0.9657**
Lq, expected queue length	**0.0012**
L, expected number in system	**0.0355**
Wq, expected time in queue	**0.00001**
W, expected total time in system	**0.00028**
Probability that data waits to be processed	**0.05%**

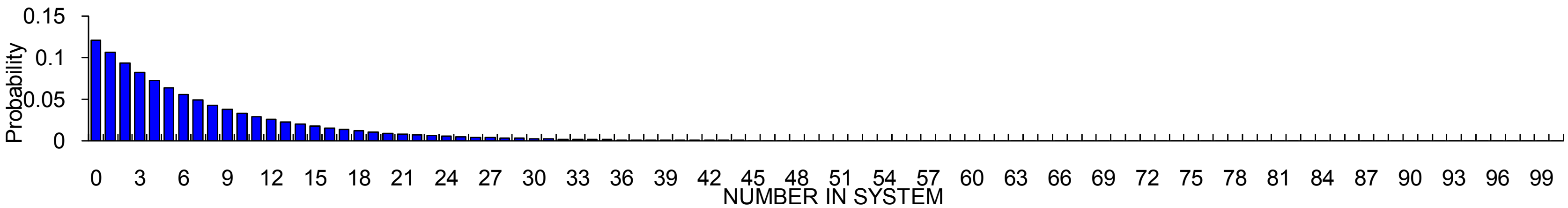

Figure H-2. Mathematical model results for 802.16 Wireless-Laptop and 802.16 Wireless -SBC systems.

This figure captures the results from the mathematical model results for Wireless-Laptop and Wireless-SBC systems.

Table H-1. Throughput Simulation for xCMA System Alternatives 1 and 2: SATCOM-Laptop and SATCOM-SBC

Single Server Queue

Calculations set to Manual. Press F9 to recalculate.

Packet #	Time between arrivals	Arrival time	Queue length	Start service	Service time	End service	Wait time	Idle Time	Average % Idle Time	Utilization Rate
0	0.00000	0.00000	0	0.00000	0.00000	0.00000	0.00000	0.0000	0%	0.00%
1	0.01034	0.01034	0	0.01034	0.00186	0.01219	0.00000	0.0103	85%	15.24%
2	0.00305	0.01338	0	0.01338	0.00005	0.01343	0.00000	0.0012	86%	14.20%
3	0.01102	0.02440	0	0.02440	0.00022	0.02463	0.00000	0.0110	91%	8.65%
4	0.00485	0.02925	0	0.02925	0.00311	0.03237	0.00000	0.0046	84%	16.20%
5	0.00097	0.03022	1	0.03237	0.00602	0.03839	0.00215	0.0000	71%	29.35%
6	0.00589	0.03612	1	0.03839	0.00325	0.04164	0.00227	0.0000	65%	34.86%
7	0.00138	0.03749	2	0.04164	0.00393	0.04556	0.00414	0.0000	60%	40.47%
8	0.02365	0.06115	0	0.06115	0.00250	0.06365	0.00000	0.0156	67%	32.90%
9	0.01237	0.07352	0	0.07352	0.00196	0.07547	0.00000	0.0099	70%	30.34%
10	0.00676	0.08028	0	0.08028	0.00378	0.08406	0.00000	0.0048	68%	31.74%
11	0.00372	0.08400	1	0.08406	0.00264	0.08670	0.00006	0.0000	66%	33.82%
12	0.00364	0.08764	0	0.08764	0.00096	0.08860	0.00000	0.0009	66%	34.18%
13	0.01119	0.09883	0	0.09883	0.00101	0.09984	0.00000	0.0102	69%	31.34%
14	0.00847	0.10730	0	0.10730	0.00528	0.11258	0.00000	0.0075	68%	32.48%
15	0.00070	0.10801	1	0.11258	0.00271	0.11528	0.00457	0.0000	66%	34.07%
16	0.00982	0.11782	0	0.11782	0.00303	0.12086	0.00000	0.0025	65%	35.00%
17	0.00158	0.11940	1	0.12086	0.00273	0.12359	0.00146	0.0000	64%	36.44%
18	0.00813	0.12753	0	0.12753	0.00100	0.12852	0.00000	0.0039	64%	35.82%
19	0.00086	0.12839	1	0.12852	0.00764	0.13616	0.00014	0.0000	61%	39.42%
20	0.00027	0.12866	1	0.13616	0.00221	0.13837	0.00751	0.0000	60%	40.39%
21	0.00092	0.12958	2	0.13837	0.00064	0.13902	0.00880	0.0000	59%	40.66%
22	0.00380	0.13337	3	0.13902	0.00118	0.14020	0.00565	0.0000	59%	41.16%
23	0.00118	0.13455	4	0.14020	0.00175	0.14195	0.00564	0.0000	58%	41.89%
24	0.00147	0.13602	5	0.14195	0.01095	0.15289	0.00592	0.0000	54%	46.05%
25	0.00115	0.13717	5	0.15289	0.00640	0.15930	0.01572	0.0000	52%	48.22%
26	0.02826	0.16543	0	0.16543	0.00391	0.16935	0.00000	0.0061	52%	47.67%
27	0.01119	0.17662	0	0.17662	0.00191	0.17854	0.00000	0.0073	54%	46.28%
28	0.00425	0.18087	0	0.18087	0.01503	0.19591	0.00000	0.0023	50%	49.86%
29	0.00983	0.19070	1	0.19591	0.00477	0.20067	0.00521	0.0000	49%	51.05%
30	0.00665	0.19735	1	0.20067	0.00344	0.20411	0.00332	0.0000	48%	51.87%
31	0.00156	0.19891	2	0.20411	0.00083	0.20494	0.00521	0.0000	48%	52.07%
32	0.00493	0.20383	2	0.20494	0.00908	0.21402	0.00111	0.0000	46%	54.10%
33	0.00797	0.21180	1	0.21402	0.00084	0.21486	0.00222	0.0000	46%	54.28%
34	0.00206	0.21386	2	0.21486	0.00017	0.21503	0.00101	0.0000	46%	54.31%
35	0.01642	0.23027	0	0.23027	0.00251	0.23278	0.00000	0.0152	49%	51.25%
36	0.00828	0.23855	0	0.23855	0.00069	0.23925	0.00000	0.0058	50%	50.16%
37	0.00930	0.24786	0	0.24786	0.00046	0.24832	0.00000	0.0086	51%	48.51%
38	0.00586	0.25371	0	0.25371	0.00236	0.25607	0.00000	0.0054	52%	47.96%
39	0.00205	0.25576	1	0.25607	0.00505	0.26112	0.00031	0.0000	51%	48.97%
40	0.00364	0.25940	1	0.26112	0.01224	0.27336	0.00173	0.0000	49%	51.25%
41	0.01180	0.27119	1	0.27336	0.00291	0.27627	0.00216	0.0000	48%	51.77%
42	0.00371	0.27491	1	0.27627	0.00169	0.27796	0.00137	0.0000	48%	52.06%
43	0.00882	0.28373	0	0.28373	0.01405	0.29779	0.00000	0.0058	47%	53.31%
44	0.00169	0.28543	1	0.29779	0.00392	0.30170	0.01236	0.0000	46%	53.92%
45	0.00967	0.29509	2	0.30170	0.00016	0.30186	0.00661	0.0000	46%	53.94%
46	0.00848	0.30357	0	0.30357	0.00071	0.30428	0.00000	0.0017	46%	53.75%

Arrival Distribution: Exponential		
=- (1/ μ)*LN(rand())		
μ =	128	Kbps

Service Distribution: Exponential		
=- (1/ μ)*LN(rand())		
μ =	235	Kbps

Based on 1 replication:	
Num of Packets	500
Average wait time (sec)	0.00276305
SD of Average wait time	0.00482715
Conf Level	95%
Alpha	5%
Conf Width of Average wait time (sec)	0.0004231
CI Low of Average wait time (sec)	0.0023399
CI High of Average wait time (sec)	0.0031862
Num of PDs	500
Average Utilization Rate	48.55%
SD of Average Utilization Rate	4.38%
Conf Level	95%
Alpha	5%
Conf Width of Average Utilization Rate	0.38%
CI Low of Average Utilization Rate	48.17%
CI High of Average Utilization Rate	48.93%
Probability that data waits to be processed	0.43%

Based on 30 replications:	
Num of Replications	30
Average wait time (sec)	0.0048588
SD of Average wait time	0.0011322
Conf Level	95%
Alpha	5%
Conf Width of Average wait time (sec)	0.0004051
CI Low of Average wait time (sec)	0.0044537
CI High of Average wait time (sec)	0.0052640
Num of Replications	30
Average Utilization Rate	55.01%
SD of Average Utilization Rate	3.77%
Conf Level	95%
Alpha	5%
Conf Width of Average Utilization Rate	1.35%
CI Low of Average Utilization Rate	53.66%
CI High of Average Utilization Rate	56.35%
Probability that data waits to be processed	0.43%

Probability that the system throughput ≥ 128 Kbps	99.57%

Data Table

Run	Avg wait time (sec)	Utilization Rate
1	0.0027630	48.55%
2	0.0062309	59.90%
3	0.0046781	59.65%
4	0.0054543	49.89%
5	0.0048863	56.17%
6	0.0080646	59.74%
7	0.0044976	57.27%
8	0.0061575	53.88%
9	0.0035393	50.23%
10	0.0039510	54.38%
11	0.0038888	52.21%
12	0.0040340	57.59%
13	0.0041	52.03%
14	0.0057	52.47%
15	0.0050	58.46%
16	0.0040	58.61%
17	0.0048	59.33%
18	0.0073	55.47%
19	0.0046	56.96%
20	0.0062	63.70%
21	0.0052	56.98%
22	0.0040	52.41%
23	0.0047	52.30%
24	0.0052	49.96%
25	0.0052	50.24%
26	0.0044	54.40%
27	0.0052	54.47%
28	0.0032	56.82%
29	0.0045	50.45%
30	0.0045	55.71%

Table H-1 summarizes the xCMA throughput simulation results using the single server queue excel spreadsheet model for the SATCOM-Laptop and SATCOM-SBC alternatives.

Table H-2. Throughput Simulation for xCMA System Alternatives 3 and 4: Wireless-Laptop and Wireless-SBC

Single Server Queue

Calculations set to Manual. Press F9 to recalculate.

Packet #	Time between arrivals	Arrival time	Queue length	Start service	Service time	End service	Wait time	Average % Idle Time	Utilization Rate
0	0.00000	0.00000	0	0.00000	0.00000	0.00000	0.00000	0%	0.00%
1	0.00897	0.00897	0	0.00897	0.00026	0.00923	0.00000	97%	2.82%
2	0.01098	0.01995	0	0.01995	0.00147	0.02142	0.00000	92%	8.09%
3	0.02646	0.04640	0	0.04640	0.00079	0.04720	0.00000	95%	5.35%
4	0.00345	0.04985	0	0.04985	0.00008	0.04993	0.00000	95%	5.22%
5	0.00140	0.05125	0	0.05125	0.00138	0.05263	0.00000	92%	7.57%
6	0.00223	0.05348	0	0.05348	0.00026	0.05374	0.00000	92%	7.90%
7	0.00508	0.05855	0	0.05855	0.00031	0.05887	0.00000	92%	7.74%
8	0.00096	0.05951	0	0.05951	0.00021	0.05973	0.00000	92%	7.99%
9	0.01878	0.07829	0	0.07829	0.00006	0.07836	0.00000	94%	6.17%
10	0.00327	0.08156	0	0.08156	0.00039	0.08196	0.00000	94%	6.38%
11	0.00707	0.08864	0	0.08864	0.00015	0.08879	0.00000	94%	6.06%
12	0.00757	0.09620	0	0.09620	0.00029	0.09649	0.00000	94%	5.87%
13	0.01365	0.10985	0	0.10985	0.00075	0.11061	0.00000	94%	5.81%
14	0.00278	0.11263	0	0.11263	0.00085	0.11348	0.00000	94%	6.41%
15	0.01091	0.12354	0	0.12354	0.00006	0.12360	0.00000	94%	5.93%
16	0.00067	0.12421	0	0.12421	0.00027	0.12448	0.00000	94%	6.10%
17	0.00746	0.13167	0	0.13167	0.00003	0.13170	0.00000	94%	5.79%
18	0.00312	0.13480	0	0.13480	0.00001	0.13481	0.00000	94%	5.67%
19	0.00164	0.13643	0	0.13643	0.00003	0.13646	0.00000	94%	5.62%
20	0.01074	0.14717	0	0.14717	0.00022	0.14739	0.00000	95%	5.35%
21	0.00671	0.15388	0	0.15388	0.00013	0.15401	0.00000	95%	5.21%
22	0.00336	0.15724	0	0.15724	0.00018	0.15742	0.00000	95%	5.21%
23	0.00489	0.16213	0	0.16213	0.00013	0.16226	0.00000	95%	5.13%
24	0.00136	0.16349	0	0.16349	0.00054	0.16403	0.00000	95%	5.41%
25	0.01270	0.17620	0	0.17620	0.00004	0.17624	0.00000	95%	5.05%
26	0.02594	0.20214	0	0.20214	0.00029	0.20243	0.00000	95%	4.54%
27	0.00606	0.20820	0	0.20820	0.00113	0.20933	0.00000	95%	4.93%
28	0.00094	0.20914	1	0.20933	0.00048	0.20981	0.00019	95%	5.15%
29	0.00209	0.21123	0	0.21123	0.00022	0.21144	0.00000	95%	5.22%
30	0.01765	0.22887	0	0.22887	0.00064	0.22951	0.00000	95%	5.08%
31	0.00885	0.23772	0	0.23772	0.00014	0.23786	0.00000	95%	4.97%
32	0.00229	0.24001	0	0.24001	0.00025	0.24025	0.00000	95%	5.02%
33	0.00525	0.24526	0	0.24526	0.00002	0.24528	0.00000	95%	4.92%
34	0.00270	0.24795	0	0.24795	0.00024	0.24819	0.00000	95%	4.96%
35	0.01316	0.26111	0	0.26111	0.00103	0.26214	0.00000	95%	5.09%
36	0.00485	0.26596	0	0.26596	0.00006	0.26602	0.00000	95%	5.04%
37	0.00384	0.26979	0	0.26979	0.00003	0.26982	0.00000	95%	4.98%
38	0.00077	0.27056	0	0.27056	0.00037	0.27093	0.00000	95%	5.10%
39	0.02161	0.29218	0	0.29218	0.00060	0.29277	0.00000	95%	4.92%
40	0.00832	0.30050	0	0.30050	0.00018	0.30068	0.00000	95%	4.85%
41	0.02616	0.32665	0	0.32665	0.00004	0.32669	0.00000	96%	4.48%
42	0.01502	0.34168	0	0.34168	0.00004	0.34172	0.00000	96%	4.29%
43	0.00733	0.34901	0	0.34901	0.00007	0.34908	0.00000	96%	4.22%
44	0.01018	0.35918	0	0.35918	0.00004	0.35923	0.00000	96%	4.11%
45	0.00915	0.36833	0	0.36833	0.00019	0.36852	0.00000	96%	4.06%
46	0.01537	0.38370	0	0.38370	0.00015	0.38385	0.00000	96%	3.94%

Arrival Distribution: Exponential		
=- (1/ μ)*LN(rand())		
μ =	128	Kbps

Service Distribution: Exponential		
=- (1/ μ)*LN(rand())		
μ =	3,729	Kbps

Based on 1 replication:	
Num of Packets	500
Average wait time (sec)	0.00000879
SD of Average wait time	0.00005519
Conf Level	95%
Alpha	5%
Conf Width of Average wait time (sec)	0.0000048
CI Low of Average wait time (sec)	0.0000040
CI High of Average wait time (sec)	0.0000136
Num of PDs	500
Average Utilization Rate	3.73%
SD of Average Utilization Rate	0.68%
Conf Level	95%
Alpha	5%
Conf Width of Average Utilization Rate	0.06%
CI Low of Average Utilization Rate	3.67%
CI High of Average Utilization Rate	3.79%
Probability that data waits to be processed	0.03%

Based on 30 replications:	
Num of Replications	30
Average wait time (sec)	0.0000081
SD of Average wait time	0.0000031
Conf Level	95%
Alpha	5%
Conf Width of Average wait time (sec)	0.0000011
CI Low of Average wait time (sec)	0.0000070
CI High of Average wait time (sec)	0.0000093
Num of Replications	30
Average Utilization Rate	3.50%
SD of Average Utilization Rate	0.37%
Conf Level	95%
Alpha	5%
Conf Width of Average Utilization Rate	0.13%
CI Low of Average Utilization Rate	3.37%
CI High of Average Utilization Rate	3.63%
Probability that data waits to be processed	0.03%

Probability that the system throughput ≥ 128 Kbp	99.97%

Data Table

Run	Avg wait time	Utilization Rate
1	0.00000879	3.73%
2	0.00001142	3.23%
3	0.00000866	4.11%
4	0.00000446	3.25%
5	0.00000794	3.07%
6	0.00000748	3.56%
7	0.00000733	3.83%
8	0.00000336	3.58%
9	0.00000710	3.72%
10	0.00000472	3.01%
11	0.00001090	3.41%
12	0.00000830	3.06%
13	0.00000696	3.46%
14	0.00001302	3.85%
15	0.00001268	3.75%
16	0.00000753	3.37%
17	0.00000736	4.15%
18	0.00000498	3.04%
19	0.00000849	2.97%
20	0.00001202	4.06%
21	0.00000219	3.68%
22	0.00000913	3.42%
23	0.00000552	3.51%
24	0.00000661	3.36%
25	0.00000690	3.24%
26	0.00001028	3.82%
27	0.00000765	3.07%
28	0.00000702	3.37%
29	0.00001740	4.20%
30	0.00000832	3.11%

Table H-2 summarizes the xCMA throughput simulation results using the single server queue excel spreadsheet model for the Wireless-Laptop and Wireless-SBC alternatives.

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APPENDIX I. LIST OF ACRONYMS

- A-

AIS	Automatic Identification System
AOI	Area of Interest

- B-

- C -

C2	Command and Control
C4ISR	Command, Control, Communications, Computers, Intelligence Surveillance Reconnaissance
CBA	Capabilities Based Assessment
CBT	Computer Based Training
CENTRIXS	Combined Enterprise Regional Information Exchange System
CMA	Comprehensive Maritime Awareness
CNO	Chief of Naval Operations
COE	Center of Excellence
COI	Community of Interest
COMMS	Communications
COMPACFLT	Command Pacific Fleet
CONOPS	Concept of Operations
CONUS	Continental United States
COTS	Commercial-Off-The-Shelf
CPU	Central Processing Unit
CRT	Cathode Ray Tubes

- D -

D-GPS	Differential Global Positioning System
DAPM	Deputy Assistant Program Manager
DEIP	Dynamic Enterprise Integration Platform
D-GPS	Differential GPS
DOD	Department of Defense
DoDAF	Department of Defense Architecture Framework
DoS	Department of State
DOTMLPF	Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel, and Facilities

- E -

ECP	Experimental Campaign Plan

- F -

FAA	Federal Aviation Administration
FFBD	Functional Flow Block Diagram
FYDP	Future Years Defense Plan

- G -

GMCOI	Global Maritime Community of Interest
GMI	Global Maritime Intelligence
GMII	Global Maritime Intelligence Integration
GMSA	Global Maritime Situational Awareness
GPS	Global Positioning System
GUI	Graphical User Interface

- H -

Hrs	Hours
HSPD	Homeland Security Presidential Directive
HSI	Human System Interface

- I -

IDEF0	Integration Definition for Function Modeling
IEEE	Institute of Electrical & Electronics Engineers
IP	Internet Protocol
IPR	In-Progress Review

- J -

JCTD	Joint Capabilities Technology Demonstration
JFC	Joint Forces Command
JOA	Joint Operations Area
JOC	Joint Operations Center

- L -

LCD	Liquid Crystal Display
LOS	Line of Sight
LRIT	Long Range Identification and Tracking

- M -

M&S	Modeling and Simulation
MAC	Media Access Control
MAUT	Multi-Attribute Utility Theory
Mbps	Megabytes per second
MDA	Maritime Domain Awareness
MHQ	Maritime Headquarters
MIEM	Maritime Information Exchange Model
MIFCLANT	Maritime Intelligence Fusion Center Atlantic
MIFCPAC	Maritime Intelligence Fusion Center Pacific
MLS	Multi-Level Security
MOC	Maritime Operations Center
MODEM	Modulator Demodulator

MOE	Measures of Effectiveness
MOP	Measures of Performance
MOTR	Maritime Operational Threat Response
MSPCC	Maritime Security Policy Coordinating Committee
MTBF	Mean Time Between Failure
MTE	Mobile Terminal Equipment

- N -

NAVEUR	Naval Command Europe
NIC	Network Interface Card
NMIC	National Maritime Intelligence Center
NORAD	North American Aerospace Defense Command
NPS	Naval Postgraduate School
NSMS	National Strategy for Maritime Security
NSPD	National Security Presidential Directive

- O -

OV	Operational View

- P -

PDA	Personal Digital Assistant
PEO C4I	Program Executive Office, Command, Control, Communications, Computers, Intelligence
PLI	Position Location Information
PMW	Program Manager, Warfare

- Q -

QFD	Quality Functional Deployment

- R -

RF	Radio Frequency

- S -

SATCOM	Satellite Communications
SBC	Single Board Computer
SDR	Software Definable Radios
SOA	Services-Oriented Architecture
SOW	Statement of Work
SPAWAR	Space and Naval Warfare Systems Command
SV	Systems View

- T -

TRL	Technology Readiness Level
TSAT	Transformational Communications Satellite

- U -

UDAP	User Defined Awareness Picture
UDOP	User Defined Operational Picture
UHF	Ultra High Frequency
UML	Universal Modeling Language
US	United States
USEUCOM	United States European Command
USNORTHCOM	United States Northern Command
USPACOM	United States Pacific Command

- V -

VHF	Very High Frequency

- X -

xCMA	Extending Comprehensive Maritime Awareness

APPENDIX J. REFERENCES

1. Andrew P. Sage, and James E. Armstrong, Jr., *Introduction to Systems Engineering,* Wiley, New York, 2000.
2. *Author*, "FORCEnet Capabilities Based Assessment of Maritime Headquarters with Maritime Operations Center Functional Needs Analysis", 2007, Draft V0.90.
3. *Author*, "Global Maritime Intelligence Integration Plan for the National Strategy of Maritime Security, October 2005", 2005.
4. Benjamin, S. Blanchard and Walter J. Fabrycky, (1998), *Systems Engineering and Analysis*, Third Edition, Prentice Hall.
5. Brian Petry, IEEE 802.16 Broadband Wireless Access Working Group, "Preliminary Draft Working Document for 802.16 Broadband Wireless Access System Requirements", 1999.
6. Chief of Naval Operations, "FORCEnet Guidance," *Memorandum for Director*, *FORCEnet, undated.* Downloaded January 2007 from http://www.chinfo.navy.mil/navpalib/policy/forcenet/forcenet21.pdf
7. CMA Architecture Team, "Comprehensive Maritime Awareness Joint Capabilities Technology Demonstration (JCTD) Concept of Operations (CMA JCTD)", 2007, pp. 6-8
8. David R. Reading, "Comprehensive Maritime Awareness JCTD, Interim Report on Architecture", Draft Version 0.2, 2007, pp 5, 30-31.
9. Dennis M. Buede, *The Engineering Design of Systems – Models and Methods,* Wiley, New York, 2000.
10. Dennis Wisnosky, *DODAF Wizdom*, Third Printing, Wizdon Systems, Inc., 2005
11. John, M. Green, "Developing an Architecture for FORCEnet and Maritime Domain Awareness, SOW MSSE Cohort #5", *Statement of Work,* 2007.
12. MIL-PRF-28800F Performance Specification, *Test Equipment for Use with Electrical and Electronic Equipment, General Specification for, 1996, pp*. 26.
13. National Research Council of the National Academies, The National Academies Press Washington, D.C., "C4ISR for Future Naval Strike Groups",

14. NSMS writing team, "National Strategy for Maritime Security", Draft working paper (2005), downloaded 8 January 2007 from http://www.whitehouse.gov/homeland/4844-nsms.pdf
15. United States Department of Homeland Security, "US Navy, National Strategy for Maritime Security: National Plan to Achieve Maritime Domain Awareness*"* (2005), pp. 1, 3. downloaded 8 January 2007 from http://www.dhs.gov/xlibrary/assets/HSPD_MDAPlan.pdf
16. United States Department of Homeland Security, "Maritime Domain Awareness, A Global Maritime Security Mission Requiring Interagency and International Cooperation and An Overarching Vision*",* downloaded from http://www.auxtdept.org/PDF/HSPD13_MaritimeSecurityStrategy.pdf
17. United States Navy*,"* National Concept of Operations for Maritime Domain Awareness*", Pre-Decisional Draft Document, (2007),* pp 1-10 and Appendix D.
18. United States Navy*, "The Concept of Operation for Fleet Maritime Domain Awareness (Fleet MDA CONOPS)", (2007),* pp.1-2, 5-6, 8, 12, 16-19, 21-22, 25-31.
19. Vern Clark, "FORCEnet: A Functional Concept for the 21st Century", Washington: Department of the Navy, 2005.
20. Vice Admiral John Morgan, and Commander Bud Wimmer, "Enhancing Awareness in the Maritime Domain:Maritime Domain Awareness is all about generating actionable intelligence, the cornerstone of successful counterterrorist and maritime and maritime law enforcement operations," *CHIPS- the Department of the Navy Information Technology online Magazine* (2005), downloaded 1 February 2007 from http://findarticles.com/p/articles/mi_m0OBA/is_2_23/ai_n15627504
21. Washington DC, White House, "National Security Presidential Directive NSPD-41/Homeland Security Presidential Directive HSPD-13", *Memorandum* (2004), downloaded 2007 from http://www.fas.org/irp/offdocs/nspd/nspd41.pdf

Throughput Sources:

22. 3 Com, "3 Com ®Gigabit Etherlink ® Server Network Interface Card" downloaded June 2007 from:

http://www.3com.com/products/en_US/detail.jsp?tab=features&pathtype=purchase&sku=3C985B-SX.

23. ATMEL, "AT91SAM9 LCD Controller", downloaded June 2007 from http://www.atmel.com/dyn/resources/prod_documents/doc6300.pdf.
24. Cable-Modem, "So which cable modem is the fastest? Five DOCSIS modems take the Tolly Group test find out the results", downloaded June 2007 from http://www.cable-modem.net/features/oct99/story1.html.
25. Cisco, "Troubleshooting Cisco Catalyst Switches to NIC Compatibility Issues, Document ID:17053" downloaded June 2007 from http://www.cisco.com/warp/public/473/46.html.
26. IEEE, "Published Standards" downloaded June 2007 from, http://grouper.ieee.org/groups/802/16/published.html.
27. Javvin Network Management and Security. "IEEE 802.16: Broadband Wireless MAN Standard (WiMAX)", downloaded June 2007 from http://www.javvin.com/protocolWiMAX.html.
28. SearchTelecom.com Definitions, "802.16", downloaded June 2007 from http://searchmobilecomputing.techtarget.com/sDefinition/0,,sid103_gci929675,00.html.

Reliability Sources:

29. Adaptec, "DUO64", ANA-62022 two-port, 64 bit PCI network interface with card for fast Ethernet Environments" downloaded June 2007 from http://www.adaptec.com/pdfs/duo64.pdf.
30. Cisco, "Voice/FAX Network Modules for the Cisco 2600/3600/3700 Routers" downloaded June 2007 from http://www.cisco.com/en/US/products/hw/routers/ps259/products_data_sheet09186a0080091ba1.html.
31. Industrial PC, "SRPC-1210A/5050A 12" and 15" Sun Readable TFT LCD panel PC Specification, downloaded June 2007 from http://www.industrialpc.com/wrkstat/srpc.htm.
32. Infomaxtek, "Peripherials – LCD Kits", downloaded June 2007 from http://www.infomaxtek.com/htm/Peripherials/LCD-K.htm.

33. LCD Panel PC Products Selection Guide, "LCD", downloaded June 2007 from http://www.icp-australia.com.au/PDF-Data/ppc5020.pdf.
34. Rugged Notebooks for Harsh Environments, Product website, downloaded June 2007 from http://www.ruggednotebooks.com/.
35. Norco Black 1U Rackmount KVM, Model KVM-15C08 downloaded June 2007 from http://www.norcotek.com/KVM-15C08.php.
36. Proxim Wireless, "MeshMAX Product Series Convergence of WiMAX, Wi-Fi Mesh and WI-Fi", downloaded June 2007 from
37. SIXNET, "MTBF Approval Letter" (modems), downloaded June 2007 from http://www.sixnetio.com/html_files/certifications/MTBF%20letter%20from%20SIXNET.pdf.
38. Winncom Technologies, "Wireless Broadband Mesh Products" downloaded June 2007 from http://www.winncom.com/moreinfo/item/9100-XX/index.html.
http://www.moonblinkwifi.com/files/DS_0207_MeshMax_A4HR.pdf.

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